



Selected Determinants of Real Estate Market Behavior and their Impact Patterns

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List of Abbreviations

CHP	Combined Heat and Power (Unit)
c.p.	ceteris paribus
ECB	European Central Bank
EPC	Energy Performance Certificate
GAM	Generalized Additive Model
GDP	Gross Domestic Products
IPCC	Intergovernmental Panel on Climate Change
OECD	Organisation for Economic Co-operation and Development
S.D.	Standard Deviation
S.E.	Standard Error
SQM	Square Meter
TR	Total Return
VAR	Vector-Autoregression, vector-autoregressive

1. Introduction

Anthropogenic actions are frequently associated with critical situations in both economic and ecological terms (Moss et al., 2010, Taylor, 2009, and Shiller, 2012). In an economic sense, these critical situations recently comprised significant turbulences and rampant risks, which ultimately peaked in a global financial crisis and recession. Stress levels were tremendous to the extent that, in order to sustain system-relevant industries and, in fact, entire economies, several central banks responded to these developments by implementing measures of monetary policy, specifically concepts of Quantitative Easing ('QE') and a reduction of the prime interest rate level.

Amidst substantial financial turbulences, another major and global concern is consorting, being anxiety regarding the worsening ecological health of planet Earth. At a higher level and in the long run, this is fueled by phenomena such as climate change and global warming, but also in short and medium terms risks are arising from issues such as extreme weather events and increasing scarcity of resources as well as excessive consumption of resources by industrialization or technological combustion. More than a few scientists take the view that these long- and short-term aspects are actually interrelated (in particular, Cook et al., 2013 and IPCC, 2014a, regarding the role of human kind as a perpetrator of climate change, Tompkins and Adger, 2004, as well as Edenhofer et al., 2012, covering possible functional chains between resources consumption and climate change as well as Stott, 2016, and Colbert et al., 2013 regarding the question, whether extreme weather events can be related to climate change).

These phenomena and their progressing development depict enormous challenges to many fields of economic activity. They also constitute changing framework conditions for real estate, as both markets actors and the industry's products are facing increased importance of topics such as resilience, security of supply and demand, the question of sustainability in business models and changing risks.

In this context, the superior goal of this dissertation is to relate the megatrends introduced to a real estate context and to analyze, in which way associated problems impact elements from the real estate value chain, essentially rental and purchasing prices or capital values, as well as market-inherent behavior.

The rest of the introductory chapter is structured as follows: section 1.1 will further specify the changing framework conditions for real estate as the underlying motivation of this thesis in greater detail. For that, selected aspects of the framework conditions will be further outlined:

section 1.1.1 describes the fundamental developments and challenges in the context of interest rate levels and connects them to real estate as both an asset class as well as an economic good. Section 1.1.2 will collect general information regarding currently intensifying extreme weather events and related damages caused to real estate, thereby outlining how extreme weather events as one manifestation of climate change depict action fields and risk factors to property owners. Section 1.1.3 will then present figures on the role of real estate in terms of resource consumption and reflect them to typical resources used in property heating, before building a bridge to heating system efficiency and renewable energy as viable solutions to the challenge.

Based on the changing framework conditions outlined, chapter 1.2 will frame the explicit research questions of the three empirical studies included in this dissertation. Chapter 1.3 will provide the publication status of the three papers and briefly touch on the variety of methodological approaches used in the empirical work, which will then be provided in chapters 2, 3 and 4 of this dissertation.

1.1. General Motivation – Changing Framework Conditions for Real Estate

From several points of view, properties and real estate investments make a difference compared to other asset classes. That is specifically due to their heterogeneity and the connected low substitutability, the duration of development processes, the relatively high investment amounts and transaction costs, the length of the life cycle as well as the stationary character of properties (Bone-Winkel/Focke/Schulte, 2016).

This leads to the initial consideration that real estate may not be comparable to other financial products or asset classes in terms of their value creation, but that it may be subject to very own and specific impact factors that drive or constrain the financial performance. These factors may not be directly significant in other asset classes such as securities or bonds or at least may show different reaction patterns in a comparative analysis.

Based on this finding, several fields of research are derived from contemporary observations on current and future mega trends in a real estate context, which reflect the current changes in framework conditions. These were identified based on extensive review of existing literature, as contained in the papers included in sections 2 to 4, as well as a selection of concepts and reports published by international associations and public authorities.

The selected observations of changing framework conditions for real estate market actors and investments comprise the following phenomena:

Table 1.1: Overview of Mega Trends and their impact on Framework Conditions

Framework Condition	Symptoms of changing framework conditions in Real Estate
Financial Framework and Investment Attractiveness	<ul style="list-style-type: none"> • Challenging Risk Diversification and Asset Allocation • Yield Compression and ABBA Strategies¹ • Concerns regarding an Upcoming Interest Shift Leap
Physical Climate Change and Extreme Weather Events	<ul style="list-style-type: none"> • Local and international efforts on managing and adapting to Extreme Weather Events, intensifying climate regulations • Increasing frequency and hazard of extreme weather events • Excessive Insurance Premia and Lack of Insurability
Inter-generational Sustainability and Resource Conservation	<ul style="list-style-type: none"> • Long-term concepts for handling property-related resources • 'German' Energy Shift • Net-Zero Energy Building Standards • Expectations on state-of-the-art of Market Participants

Source: own collection, based on Stevens, 2017, Liow and Schindler, 2017, Stott, 2016, Hirsch, Braun and Bienert, 2015, IPCC, 2012, and Li, Yang, and Lam, 2013.

While table 1.1 serves to give an overview of the changing framework conditions for real estate, they will be exemplified and further discussed in chapters 1.1.1. to 1.1.3. In particular, three aspects appear expedient for related research to be conducted in this work:

1. In the light of economic turbulences and uncertainty, whether and to which extent real estate is subject to macro-economic determinants and how a change in these determinants (such as an interest leap) influences rents and capital values
2. In the light of increasing risks from extreme weather events, whether and to which extent real estate is subject to increased flood risk and specifically how this risk influences residential rents and housing prices
3. In the light of substantially decreasing reserves in natural resources, whether and to which extent real estate is subject to changing environmental awareness and action, specifically the implementation of modern heating technology, including technology fueled by renewable energy sources.

These topics were identified and selected with the purpose of gaining a profound understanding of how they impact or interact with real estate performance. It is expected that

¹ 'ABBA' describes the investment strategy of diversification the portfolio by incorporating A-grade properties or A-micro locations in subprime ('B') cities or B-grade properties or B-micro locations in core ('A') investment locations, cf. Swiss Life AM, 2017.

both the economic and the ecological circumstances mentioned before come with respective economic impact and developments.

This thesis aims to create an extended understanding and a large bandwidth of empirical evidence on the framework conditions mentioned before and their impact in a real estate context. This comprises both the question of significance for property performance as well as specific market reactions and market behavior patterns.

1.1.1. A paradigm change in economic environments and interest rate policy

In terms of economic turmoil, the international economy survived multiple global-scale recessions already at the beginning of the 21st century, which have peaked in the financial breakdown of 2009 for the moment. In this context, real assets were found closely linked to this global financial crisis. The connection is both of indirect nature, through the breakdown of mortgage markets due to excessive non-performing loans, as well as of direct nature due to sudden shocks in valuation, lower prices from forced sales and lower demand from lower affordability or illiquidity (Favara and Giannetti, 2017; Jarsulic, 2012). However, the industry plays a dual role: on the one hand side, property investments and financing have contributed to what ultimately resulted in the current low-interest rate environment;² on the other hand side, the interest low determines real estate prices and performance today and in a longer term.

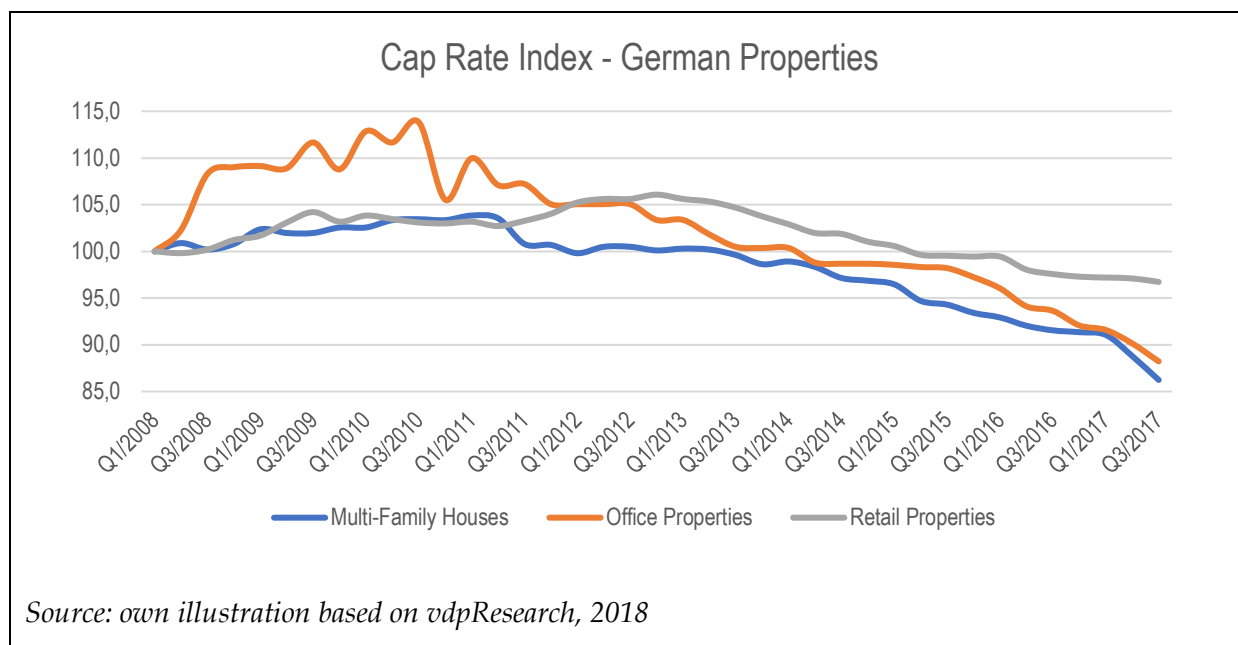
Several programs of the European Central Bank were implemented in order to primarily react to countries increasing their debt levels to manage the consequences of the financial crisis and to countries backing their economic stability, even though these reactions themselves constitute further fiscal risks in the form of asset price inflation, pricing exaggerations or overheating tendencies (Dreger and Kholodilin, 2013).

Investment volumes have increased ever since throughout the property market segments with a lot of this development being caused by higher affordability and higher liquidity due to lower interest payments and debt service volume. Exaggerations in pricing, however, have been a side effect of this development, as the supply of new properties has not kept up with the significantly increased demand. Also, the lack of profitable investment alternatives in the low-interest environment has led to investment pressure amongst national and international

² After all, real estate as an asset class was not quite unblameable regarding the evolution of the crisis. Specifically, the US mortgage crisis rooted in residential real estate-related decisions and developments, which put pressure on institutional and private investors globally as well as across segments and asset classes due to internationally connected capital flows.

capital allocators, which caused the mentioned exaggerations mainly in sales markets. It should not go unmentioned that rent markets have decoupled from this development. Therefore, a significant yield compression has gone hand in hand with this (BNP Paribas Real Estate, 2017), as shown in the following illustration.

Figure 1.1: Cross-Segment Cap Rates in Germany, 2008-2017



Yet, institutional investors have, on average, significantly increased the real estate share of their portfolios throughout the recent years (Syrjaenen, 2017). Amongst other reasons, real estate is believed to be one of the few asset classes for yield outperformance also in times of investment pressure due to cheap capital and an intensified capital investment pressure with fewer options for asset allocation. Also, real estate is regarded a good instrument for diversification due to low correlation with other asset classes (Credit Suisse, 2014).

On the one hand, economic theory and intuition suggest that, as interest rates drive liquidity in the market, property prices are negatively impacted by the interest level and housing prices increase when interest rates decrease (David, 2013). And at the same time, investors might fear that increasing interest rates or even an interest leap in the future could lead to an erosion of property values and turmoil on real estate markets. On the other hand, however, early economic research has already shown how asset price inflation happened despite of increasing interest rate levels (described as 'Gibson's paradox' in Keynes, 1930), therefore questioning the

actual role of interest rates in property markets. This is the core aspect of the first empirical study included in this dissertation.

Key Objectives of the Study

Long-term cycles of economies and interest-rate patterns are frequently characterized by uptrends and downturn. The study included in section 2 analyzes,

- Whether there is a significant impact of interest rates and other macro-economic determinants and commercial property markets, and
- What the reaction pattern of real estate throughout economic and interest cycles looks like over time.

1.1.2. Intensifying extreme weather events

Ecological framework conditions are changing dramatically. Humankind is predominantly believed to be responsible for anthropological climate change that comes with both long- as well as short-term effects. Aside of long-term developments such as increasing sea levels and changing land use structures both inside and outside coastal areas, these occurrences comprise different types of extreme weather events such as storms, droughts or floods, which can lead to dramatic damages in the short-term – including damages or destruction of properties from landslides or forest fires. (IPCC, 2014b)

In 136 years of climate observation, sixteen of the seventeen warmest years have occurred since the year 2001. 2016 ranks as the warmest year ever at 0.99 degrees Celsius above the mid-20th century average (NASA, 2017). Real estate as an economic good is diversely impacted by the changes in climatic conditions. Aside of long-term implications such as the deterioration of property locations due to limited usability or accessibility, specifically extreme weather events (such as storms, hails, heatwaves, draughts or floods), which can cause significant financial damage on a very short-term basis, are considered relevant. The following table gives an overview of selected climatic aspects and how they influence real estate values.

Table 1.2: Climatic Aspects and their Real Estate-related Impacts

Climatic Aspects	Residential and commercial property values
Increasing Surface Temperatures	Reduced income potential due to higher operating costs (leading to reduced net rents at constant willingness to pay by tenants)
Extreme Weather Events	Damaged building substance, rent reductions, increased insurance fees
Climate Regulation	Environmental taxation, increasing standards in building quality (with the potential to result in higher construction costs)
Rising Sea Levels	Decreased fungibility, lack of future viability of occupancy

Source: collection based on Bienert, 2014.

The former prioritization of goals in social and economic activity has led to meteorological, hydrological, biological and ecological deficiencies, which human kind summarizes under the term of ‘climate change’³. In that sense, climate change depicts more than the simple increase of surface temperature. Although the functional chains are complex and still not fully explored, massive impairments are revealed consequently. As of today, especially extreme weather events and their development in intensity and frequency are indicative of progressing climate change. In this context, the following table gives an overview of selected recent extreme weather events in the U.S. that caused damages in a ten-digit range. The table also outlines the specific relevance for real estate.

Table 1.3: Extreme Weather Events and their Economic Damages (> 1 billion US dollars)

Event (date), location	Estimated Financial Damage	Real Estate Implications
Flooding (March 2016) Texas and Louisiana, USA	1.5 – 3.1 billion US dollars	1,000 residential and commercial properties damaged or destroyed
Flooding (August 2016) Louisiana, USA	7.0 - 13.0 billion US dollars	50,000 residential properties damaged or destroyed
Severe Hurricane and Flooding (October 2016) Southeast U.S.	7.0 – 11.5 billion US dollars	100,000 residential properties damaged or destroyed

Source: NOAA, 2017

³ While intensifying climate regulation also depicts a major changing framework condition, this introductory section focuses on extreme weather events and challenges arising from that specifically in line with the following empirical study.

Although properties have a long historical track record of being exposed to risks connected with extreme weather events, climate change has significantly increased the presence and risk potential of these occurrences. For instance, the median annual expected losses from tropical storms is expected to increase by 30 % until 2040, from floods even by 65 % (Bouwer, 2010 and Bouwer, 2011). Indirect consequences additionally include effects such as increasing insurance premiums or declining touristic frequency or lower rents from regressing attractiveness of a region. And as people spend up to 90 % of their lifetime in residential, commercial and other properties (Klepeis et al., 2001), the adaption of their construction and management to new climatic givens is of essential interest.

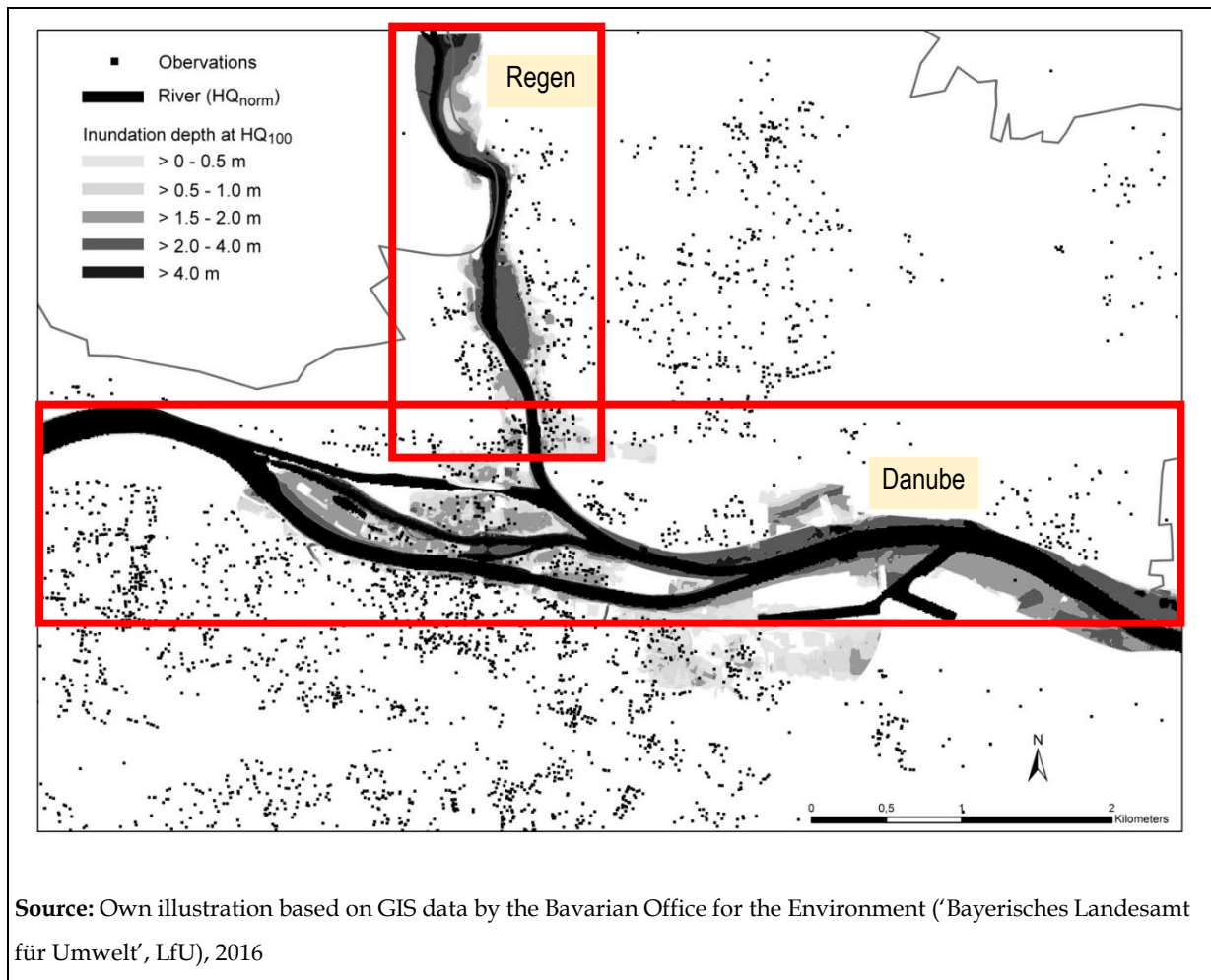
And while prior research has developed theoretical concepts on property damage risks and potential hazard volumes of extreme weather events (Hirsch, Braun, and Bienert, 2015), it stays unclear, how the consideration of extreme weather risks is reflected empirically in market behavior. And more specifically and with focus on flood events, the question arises, how these events are priced into property markets and price structures therein. On that basis, changing requirements from a demand side or changing expectations from the supply side could be identified and quantified, which is the core aspect of the second study in this dissertation.

Key Objectives of the Study

To both property owners and the insurance industry, flood risk brings the need for transparency and assessment (Merz et al, 2010). Therefore, the study in section 3 will analyze,

- Whether there is a significant correlation between flood risk and property rents as well as purchasing prices of residential property, and
- Quantify the impact of flood risk on German housing markets, exemplified by the City of Regensburg with three essential rivers Danube and Regen (cf. figure 1.2) as well as the river Naab close by.

Figure 1.2: Observations of the Flood Risk study in the local river context



1.1.3. Expiring resources for property heating

In fact, extreme weather events depict only one of the drivers of the new target accentuation towards sustainability. In other definitions, sustainability considerations are largely motivated by the question of intergenerational justice and the discovery of a long-term tightening of natural resources (UNECE, 2004). In that sense, real estate faces changing framework conditions in terms of shortening natural resources as well as increased awareness, which will further stress the importance of conserving resources for future generations.

As real estate and construction are estimated to be responsible for approximately 30 to 40 % of resource consumption globally, the industry and the technology used by it play a major role in ecological resource management and for solving related scarcity challenges (World Economic Forum, 2016). Essential levers in solving these issues, also in the light of intergenerational justice, could be the shift towards the increased consumption of renewable

resources as well as the improvement of energy efficiency in properties fueled by non-renewable resources. And indeed, the over-consumption of resources as well as the lack in renewability of certain resources depict future risks for the planet already today. Also, the overexploitation of non-renewable resources is revealed already today as a perspective problem with current and future topicality (Motesharrei, Rivas, and Kalnay, 2014). To elaborate a comprehensive picture of the necessity and urgency of the issue, the following illustration gives a brief overview of several non-renewable resources as well as their future reach based on current production levels.

Figure 1.3: Static Reach of Known Non-Renewable Resource Reserves

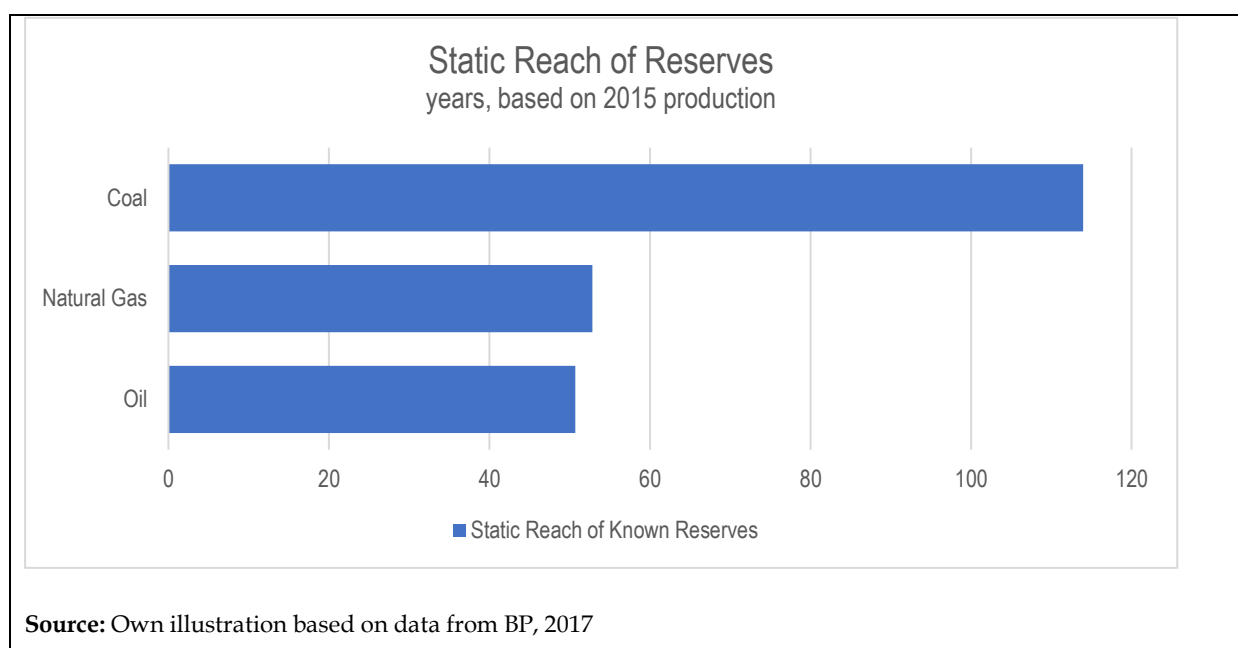


Figure 1.3 shows that a shift toward renewable energy sources and a general decrease of fossil energy consumption are essential for a future-proof energy solution on a global scale.

And in fact, amongst other institutions, the European Union has demanded an increase in renewable energy sources as a future common goal (European Commission, 2017). Meanwhile, research and development have proven that progress on enhancing the share of renewable energy sources or improving the efficiency of fossil technology are possible, which is specifically observed in the efficiency of heating technology in a property context and comes with potential for ecological improvement (Thomson and Liddell, 2015). Nevertheless, the actual diffusion of such technology still is low and below requirements to reach global environmental goals (Karkaya and Sriwannawit, 2015; Yaqoot, Diwan, and Kandpal, 2016).

Approaches for the extended diffusion of respective technology could be established by either sanctioning obsolete technology, for instance by legal intervention or standardization of norms, or by providing incentives towards modern alternative technologies; these measures could be direct subsidies or tax alleviations (Sardianou and Genoudi, 2013). While most of these are rather public-sector instruments, it stays unclear whether there are market-inherent incentives and behavioral patterns, such as higher prices driven by the utilization of state-of-the-art heating technology or renewable energy sources. This is the core aspect of the third empirical study in this dissertation.

Key Objectives of the Study

There is a strong political will towards an energy-efficient, resource-saving and environmental-friendly real estate industry. The study in section 4 will therefore analyze,

- Whether there are indications for market-based incentives aside of political pressure, which could promote the diffusion of modern building heating technology, including renewables-based heating, and
- Identify and quantify a 'clean pay-off' from modern heating technology in market-oriented pricing patterns.

1.2. Research Questions

In accordance with the focal areas of the underlying research papers, the following research questions have been developed, postulated and answered in this dissertation.

Research Paper 1: Office properties through the interest cycle: Performance impact and economic sustainability in Germany

- Which macro-economic determinants are suitable and frequently considered for analyzing economic interplay in a property context?
- How do sudden impulses in macroeconomic fundamentals translate into responses in office performance and which are the most essential determinants?
- What is the specific impact of the prime interest rate and what does the reaction pattern in terms of office rents and capital values look like over time?

Research Paper 2: How flood risk impacts residential rents and property prices – empirical analysis of a German property market

- Is there a significant relationship between flood risk as one manifestation of extreme weather events and residential rents and purchasing prices?
- Does specifically the supply side of a regional property market integrate such risk in pricing considerations?
- What does the respective impact of flood risk look like and which strength can be attributed to this risk?

Research Paper 3: Does ‘clean’ pay off? Housing markets and their perception of heating technology

- What is the effect of installing state-of-the-art heating technology, including systems based on renewable fuel types, on residential rents and purchasing prices in Germany?
- How does this effect compare to price structures of buildings with obsolete or fossil heating technology?
- How can non-radial and non-linear land-use data as well as cartographic information be utilized to improve hedonic pricing models in terms of expressiveness towards regional property pricing effects?

1.3. Course of Analysis

All the papers included in this dissertation show a strong focus on empirical findings and expressiveness based on clear quantitative methodology. The mix of underlying methodology is diverse and was selected based on the given data and the target of the analysis.

The two major concepts beyond the studies were Vector-Autoregressive Models (‘VARs’) for those parts of analysis, where market-level time series information was in the focus of interest, while the studies that comprise the evaluation of information from property-level were performed under application of Generalized Additive Models (‘GAMs’) with extra geographical reference, advancing them towards ‘Geo-Additive Models’. While further details on the respective methodology will be outlined in the respective chapter, the following list gives an overview of the research papers included in this dissertation as well as its status at the time of submission of the thesis.

Chapter 2: Office properties through the interest cycle: Performance impact and economic sustainability in Germany

- Status: accepted for review, accepted for publication, published
- Authors: Jonas Hahn, Verena Keil, Thomas Wiegelmann, Sven Bienert
- Submission to: Journal of Property Investment and Finance
- First Submission: 22.01.2016
- Accepted for publication: 14.05.2016
- Quotation: Journal of Property Investment and Finance, Vol. 34, No. 5

Chapter 3: How flood risk impacts residential rents and property prices – empirical analysis of a German property market

- Status: accepted for review
- Authors: Jens Hirsch, Jonas Hahn
- Submission to: Journal of Property Investment and Finance
- First Submission: 11.11.2016
- Accepted for publication: 22.04.2017
- Quotation: Journal of Property Investment and Finance, Vol. 36, No. 1

Chapter 4: Does ‘clean’ pay off? Housing markets and their perception of heating technology

- Status: submitted
- Authors: Jonas Hahn, Jens Hirsch, Sven Bienert
- Submission to: Property Management
- First Submission: 28.08.2017 (Property Management)
- Accepted for review: 31.08.2017
- Received Referee Feedback, in editorial process

1.4. References

Bavarian Office for the Environment, 2016: “[Information Service – Flood Risk Areas]”, http://geoportal.bayern.de/bayernatlas/iug/?theme=wasser_hochwassergefahren_fl_aechen, available in German, accessed 13.10.2016.

- Bienert, S., 2014: “Extreme weather events and property values – assessing new investment frameworks for the decades ahead”, ULI Europe Policy 6 Practice Committee Report, Urban Land Institute, London.
- BNP Paribas Real Estate, 2017: “European Office Prospects November 2017”, https://www.realestate.bnpparibas.com/sites/default/files/2017-12/PR%20Research_European%20Office%20Prospects_ENG.pdf, accessed 07.01.2018.
- Bone-Winkel, S., Focke, C., and Schulte, K.-W., 2016: „[Terminology and Characteristics of Real Estate as an Economic Good]“, in Schulte, K.-W., Bone-Winkel, S., and Schäfers, W. (Eds.): “Real Estate Economics I – Commercial Basics”, 5th Edition, Berlin, pp. 3-25 (in German).
- Bouwer, L., 2010: “Disasters and climate change: analyses and methods for projecting future losses from extreme weather”, dissertation, Vrije Universiteit, Amsterdam.
- Bouwer, L., 2011: “Have disaster losses increased due to anthropogenic climate change?”, Bulletin of the American Meteorological Society, Vol. 92, No. 1, pp. 39-46.
- BP, 2017: “Statistical Review of World Energy 2017”, <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>, accessed 07.01.2018
- Colbert, A., Soden, B., Vecchi, G., and Kirtman, B., 2013: “The Impact of Anthropogenic Climate Change on North Atlantic Tropical Cyclone Tracks”, Journal of Climate, Vol. 26, pp. 4088-4095.
- Cook, J., Nuccitelli, D., Green, S., Richardson, M., Winkler, B., Painting, R., Way, R., Jacobs, P., and Skuce, A., 2013: “Quantifying the consensus on anthropogenic global warming in the scientific literature”, Environmental Research Letters, Vol. 8, No. 2, pp. 1-7.
- Credit Suisse, 2014: “Real Estate as an Asset Class”, White Paper, available at <https://www.credit-suisse.com/media/production/asset-management/docs/real-estate/white-paper-real-estate-as-an-asset-class.pdf>, accessed 07.01.2018.
- David, N., 2013: “Predicting housing prices according to expected future interest rate”, Applied Economics, Vol. 45, No. 21, pp. 3044-3048.
- Dreger, C., and Kholodilin, K., 2013: “Real Estate Booms and Price Bubbles: What Can Germany Learn from Other Countries?”, DIW Economic Bulletin, No. 6/2013, pp. 16-24.

- Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., Stechow, C., 2012: "Special Report on Renewable Energy Sources and Climate Change Mitigation", Summary for Policymakers and Technical Summary, IPCC Working Group III (Mitigation), pp. 5-26.
- Ernst & Young, 2017: "[Trend Barometer Real Estate Investments in Insurances 2017]", available at [http://www.ey.com/Publication/vwLUAssets/ey-trendbarometer-immobilienanlagen-der-assekuranz-2017/\\$FILE/ey-trendbarometer-immobilienanlage-n-der-assekuranz-2017.pdf](http://www.ey.com/Publication/vwLUAssets/ey-trendbarometer-immobilienanlagen-der-assekuranz-2017/$FILE/ey-trendbarometer-immobilienanlage-n-der-assekuranz-2017.pdf), last access on 07.01.2018, in German.
- European Commission, 2017: "Renewable energy - Moving towards a low carbon economy", <https://ec.europa.eu/energy/en/topics/renewable-energy>, last accessed 07.01.2018.
- Favara, G., and Giannetti, M., 2017: "Forced Asset Sales and the Concentration of Outstanding Debt: Evidence from the Mortgage Market", *The Journal of Finance*, Vol. 72, No. 3, pp. 1081-1118.
- Favero, C., 2016: "Demographics and the Behavior of Interest Rates", *IMF Economic Review*, Vol. 64, No. 4, pp. 732-776.
- Hirsch, J., Braun, T., and Bienert, S., 2015: "Assessment of climatic risks for real estate", *Property Management*, Vol. 33, No. 5, pp. 494-518.
- IPCC, 2012: "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation – Summary for Policymakers", A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, NY, USA, pp. 1-19.
- IPCC, 2014a: "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", [Core Writing Team Pachauri, R., and Meyer, L. (eds.)]. IPCC, Geneva, Switzerland, pp. 1-151.
- IPCC, 2014b: "Climate Change 2014: Impacts, Adaption and Vulnerability. Summary for Policymakers. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", [Field, C., Barros, V., Dokken, D., Mach, K., Mastrandrea, M., Bilir, T., Chatterjee, M., Ebi, K., Estrada, Y., Genova, R., Girma, B., Kissel, E., Levy, A., MacCracken, S., Mastrandrea, P., and White, L. (eds.)]. IPCC, Geneva, Switzerland, pp. 1-32.

- Jarsulic, M., 2012: "Anatomy of a Financial Crisis: A Real Estate Bubble, Runaway Credit Markets", Palgrave Macmillan: New York.
- Karakaya, E., and Sriwannawit, R., 2015: "Barriers to the adoption of photovoltaic systems: The state of the art", *Renewable and Sustainable Energy Reviews*, Vol. 49, September 2015, issue C, pp. 60-66.
- Keynes, J., 1930: "A Treatise on Money", Harcourt Brace & Company: New York.
- Klepeis, N., Nelson, W., Ott, W., Robinson, J., Tsang, A., Switzer, P., Behar, J., Hern, S., Engelmann, W., 2001: "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants", *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 11, No. 3, pp. 231-252.
- Li, D., Yang, L., and Lam, J., 2013: "Zero energy buildings and sustainable development implications – A review", *Energy*, Vol. 54, No. 1, pp. 1-10.
- Liow, K., and Schindler, F., 2017: "Linkages between office markets in Europe: a volatility spillover perspective", *Journal of Property Investment & Finance*, Vol. 35, No. 1, pp. 3-25.
- Machaj, M., 2016: "Can the Taylor Rule Be a Good Guidance for Policy? The Case of 2001-2008 Real Estate Bubble", *Prague Economic Papers*, Vol. 25, No. 4, pp. 381-395.
- Motesharrei, S., Rivas, J., and Kalnay, E., 2014: "Human and nature dynamics (HANDY): Modeling inequality and use of resources in the collapse or sustainability of societies", *Ecological Economics*, Vol. 101, May 2014, p. 90-102.
- Merz, B., Kreibich, H., Schwarze, R., Thieken, A., 2010: "Assessment of economic flood damage", *Natural Hazards and Earth System Sciences*, Vol. 10, No. 8, pp. 1697-1724.
- Moss, R., Edmonds, J., Hibbard, K., Manning, M., Rose, S., Vuuren, D., Carter, T., Emori, S., Kainuma, M., Kram, T., Meehl, G., Mitchell, J., Nakicenovic, N., Riahi, K., Smith, S., Stouffer, R., Thomson, A., Weyant, J., and Wilbanks, J., 2010: "The next generation of scenarios for climate change research and assessment", *Nature*, Vol. 463, pp. 747-756.
- NASA, 2017: "Global Climate Change - Vital Signs - Global Temperature", <https://climate.nasa.gov/vital-signs/global-temperature/>, last access 07.01.2018.
- NOAA, 2017: "U.S. Billion-Dollar Weather & Climate Disasters 1980-2017", <http://ncdc.noaa.gov/billions>, last access 07.01.2018.

- Sardianou, E., and Genoudi, P., 2013: "Which factors affect the willingness of consumers to adopt renewable energies?", *Renewable Energy*, Vol. 57, issue C, September 2013, pp. 1-4.
- Shiller, R., 2012: "The Subprime Solution: How Today's Global Financial Crisis Happened, and What to Do about It", Princeton
- Stevens, S., 2017: "The public markets and European residential real estate.", *Housing Finance International*, Vol. 31, Autumn 2017, pp. 24-29.
- Stott, P., 2016: "How climate change affects extreme weather events", *Science*, Vol. 352, No. 6293, pp. 1517-1518.
- Swiss Life AM, 2016: Swiss Life Asset Managers launches open-ended mutual property fund "Swiss Life Living and Working", https://www.swisslife-am.com/en/media/news/feed/2017/20161207_purchase_basel.html, accessed 29.12.2017.
- Taylor, J., 2009: "Getting Off Track: How Government Actions and Interventions Caused, Prolonged, and Worsened the Financial Crisis", Stanford 2009.
- Thomson, H., and Liddell, C., 2015: "The suitability of wood pellet heating for domestic households: A review of literature", *Renewable and Sustainable Energy Reviews*, Vol. 42, February 2015, pp. 1362-1369.
- Tompkins, E., and Adger, W., 2004: "Does adaptive management of natural resources enhance resilience to climate change?", *Ecology and Society*, Vol. 9, No. 2, pp. 1-14.
- UNECE, 2005: "Sustainable development - concept and action", http://unece.org/oes/nutshell/2004-2005/focus_sustainable_development.html, last access 07.01.2018.
- vdpResearch, 2018: "German Property Price Index Q3/2017", http://www.vdpresearch.de/wordpress/wp-content/uploads/2017/11/vdp_Immobilienpreisindex-vdp_Property_Price_Index_QI2003-QIII2017.xlsx, last access 07.01.2018.
- World Economic Forum, 2016: "Environmental Sustainability Principles for the Real Estate Industry", World Economic Forum Industry Agenda Council on the Future of Real Estate & Urbanization, Geneva.

Yaqoot, M., Diwan, P., and Kandpal, T., 2016: "Review of barriers to the dissemination of decentralized renewable energy systems", *Renewable and Sustainable Energy Reviews*, 2016, Vol. 58, May 2016, issue C, pp. 477-490.

2. Office properties through the interest cycle: Performance impact and economic sustainability in Germany

Purpose – The purpose of this paper is to estimate the impact of changes in macro-economic conditions going forward, focusing on a change in interest policy, with regard to office letting and investment markets.

Design/methodology/approach – For this analysis, the authors constructed two vectorautoregressive models, measuring the response of office rents and capital values in Germany to economic impulses. The authors isolated effects of unique exogenous positive shocks (such as economic growth or interest leaps) on the basis of impulse-response functions in order to understand the complex dynamic interdependence between several economic factors and office performance changes.

Findings – The authors initially find a moderately positive development of both office performance components even although supposing an increase in interest level. In terms of capital values, the authors find that they do not drop before 1.5 years after the interest impulse and the negative effect peaks after approximately nine quarters. Furthermore, the reaction to a change in GDP is significantly lower than a reaction to the interest rate, but impulses in other macro-economic factors provoke stronger reactions. Finally, the authors find that a positive interest shock leads to a comparably robust development and economic sustainability in office rents throughout a consideration horizon of 24 quarters.

Research limitations/implications – Estimations are based on observations from a time period containing two rather extraordinary market phases. As they included bubble growth and the low-interest environment, the authors find that certain patterns in both phases neutralize each other when looking at the total time frame. The authors constructed sub-samples to compensate for this. However, the research does not provide to what extent the measured impulse-responses stay forecast-proof, if the market moves into a phase of short-term normalization.

Practical implications – This paper provides insights into estimated impulse-response patterns on a hypothetical sudden increase of several macro-economic determinants. On this basis, the probable reaction to an increase in, for example, the interest rate level can be approximated. Also, the paper provides a fundamental understanding of the economic sustainability of German office properties in terms of their value and rent performance in the case of exogenous shocks.

Originality/value – This paper contains the first vector-autoregressive, impulse-response analysis of office markets in Germany in the context of several macro-economic drivers, including the interest level. It delivers insights into market reaction patterns on the basis of simulated one standard deviation shocks in all included variables.

2.1. Introduction

More than seven years after the Lehman breakdown, the whole investment industry is still deeply impacted by the consequences of the financial crisis. One of its major consequences is that monetary policies have changed fundamentally – and so have real estate markets. The interaction of interest rates, credit demand, the lack of appropriate alternative investments and the high liquidity in the market led to a property boost, which can be observed by the means of decreasing yields in the office investment segment. This transmission of monetary policy impulses depicts a calculated mechanism to compensate general economic downturns (Schaetz and Sebastian, 2011; Deutsche Bundesbank, 2012). Already in 2008, with the financial crisis causing major challenges and setbacks of unknown dimension for the economy, the European Central Bank took several measures that exceeded the conventional monetary policy in order to increase impact and effectiveness (European Central Bank, 2009).

As the vigorous effect of these measures still turned out to be insufficient and the prime rate level had arrived close to the zero level, several additional medium-term measures on quantitative easing were announced between June 2014 and January 2015 – also aiming to achieve stability in inflation and to further extend lending. Following the Archer and Ling (1997) model of real estate markets, we base this work on the close interdependency not only between different market segments, but also with external systems such as capital markets or national (macro-) economics.

While the whole Euro area experiences progress in its economic recovery at expected growth rates of 1.3 per cent in 2015 and 1.7 per cent in 2016, differences within the nations were tremendous in the past (OECD, 2015). For instance in 2010, the German economy grew by 4.0 per cent – double the average growth rate of the Euro area. Other nations such as Spain have not really recovered from the bust since 2009.

Already in Q4/2014, the economic output exceeded expert forecasts by 0.8 per cent points (German Council of Economic Experts, 2015). Also the sentiment and assessment of the business climate has increased in Q2/2015 to the second highest value since the crisis. And ultimately, unemployment has reduced to the lowest level since 1991 with continuing high demand for workforce. But not only do we observe a good economic development in Germany overall, but also office letting and investment markets have benefited from these good framework conditions. At the peak of the financial crisis, especially foreign real estate investors dropped massively from the German office market, after having dominated

especially the large-volume transaction with a 90 per cent share (Just, 2010). The overall commercial transaction volume decreased by almost two-thirds to less than 20 billion Euros compared to 2007 (JLL, 2009). Office markets were in this context affected above average due to their high sensitivity to economic changes and higher volatility than, for instance, residential property markets (Just, 2010). However, for 2014, the German office investment segment has reached new record highs of 17.5 billion Euros (a 44 per cent share of 40 billion Euros in total transaction volume (JLL, 2015). And specifically, the share of investments from Asia has quadrupled from 1.5 to 6.0 per cent (Savills, 2014). While it appears notable that offices were replaced by retail properties accounting for the highest share of investment volume, generally, there is a clear tendency towards the pre-crisis investment level also in the office segment (Figure 1).

The high and increasing demand for office investments in Germany has led to a further compression of prime yields. For the sixth year in a row, yields have been decreasing and Germany's top locations quote between 25 and 45 basis points below 2007's average (BNP Paribas Real Estate, 2015a; Atisreal, 2009). This results in crowding out effects in terms of higher demand for non-core investments such as B-grade offices in A locations or even A-grade offices in B locations (Savills, 2014). As illustrated in Figure 2, also the spread between German Government bonds and prime yields has reached a record high of 411 basis points in Q1/2015 (with a slight correction to 384 basis points in Q2/2015), which indicates a further increase in attractiveness of German real estate. This is also backed by the high level of political stability in Germany, as global investor tend to invest into resilience during turbulent times.

Indeed, an argument could be made from this at the current point that the long range evident coherence of a low-interest level and a positive real estate investment performance could already be achieved by the short- to medium-term correction policies of the ECB.

However, due to the rare characteristics of current market-driven circumstances such as a high level of investment pressure amongst capital owners, unavoidably low-interest levels and the liquidity glut as well as a low supply in terms of new construction or retrofits in the office segment, the question remains how sustainable the increased attractiveness is, respectively, how fundamental real estate investment performance has improved under these circumstances.

Figure 2.1: The development of office investment volume in Germany

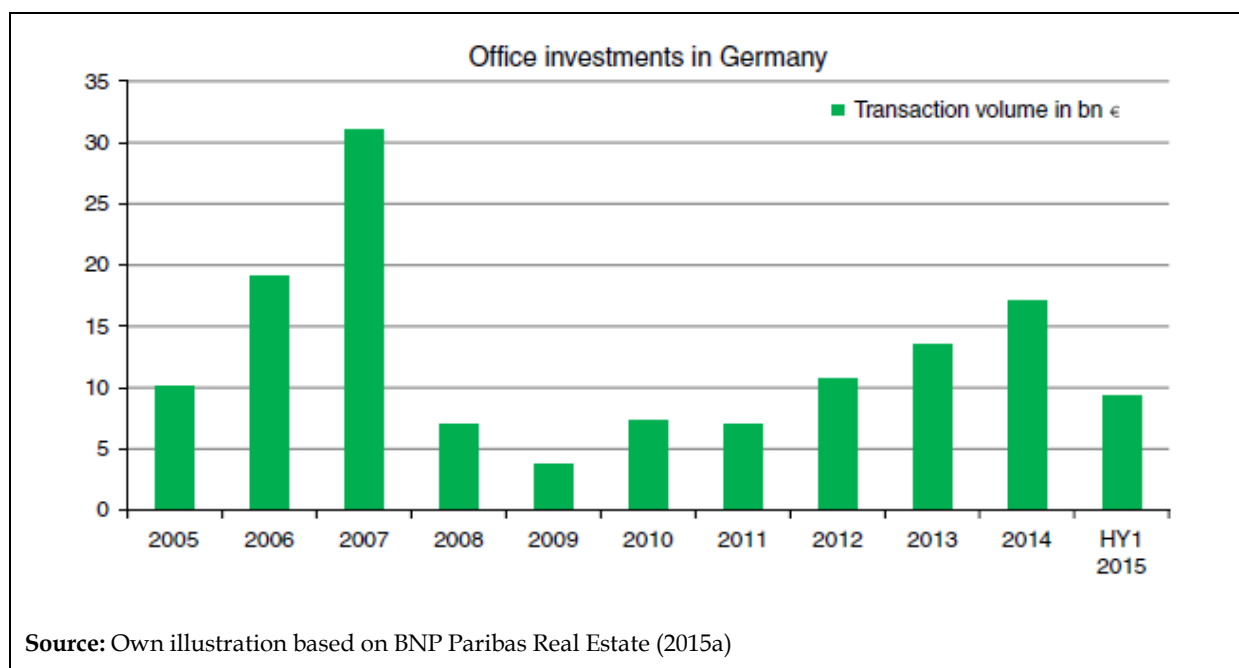
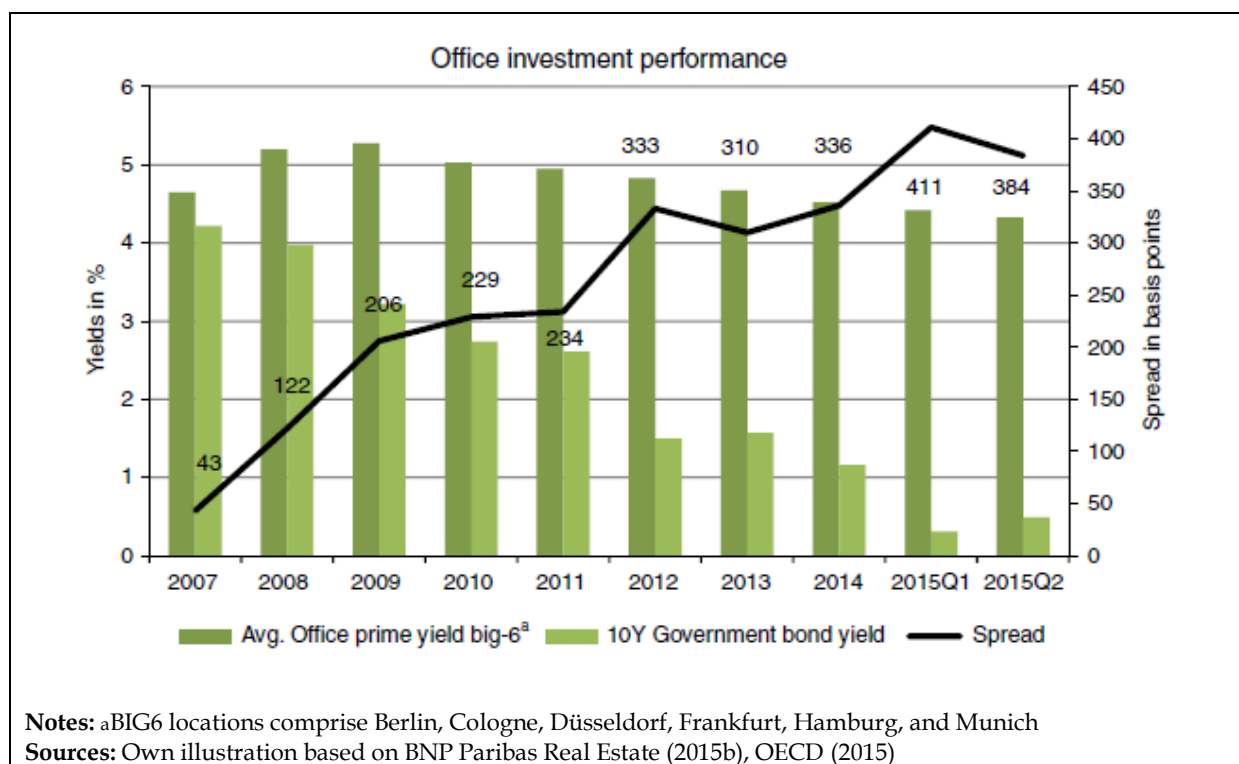


Figure 2.2: A yield comparison of aBIG6 office investments and government bonds



2.2. Review of literature

Research on the correlation between economic fundamentals, the interest rate as well as the specific performance of real estate has experienced a rise in research attention. In a general literature consideration on interest rates and their economic implications, specifically Shiller (2007) provided fundamental groundwork by analysing and questioning the long-term relationship of low-interest rates and high asset prices, and points out the importance of public belief and economic framework conditions, such as the perception of real interest rates. Before that, already Wicksell (1907) and Keynes (1930) suggested that a paradox can be found (labelled as Gibson's paradox) that under then unknown conditions, prices may inflate also in times of higher interest levels. As we investigate more recent analysis on policy and markets in the low-interest rate environment, Japan serves as a good example for observation due to a longer period of forced low-interest environment. In this context, Fujiki and Shiratsuka (2002), Fujiki and Shioji (2006) as well as Akram and Das (2014) have investigated the economic impacts arising from Japan's long-term low-interest phase. While focusing rather on financial assets (such as government bonds) or the policy perspective, these authors find evidence that behavioural aspects as well as economic framework conditions are driving or constraining the impact of interest measures overall. In their research, Kablau and Weiss (2014) discuss the impact of low-interest rates on the life insurers' solvency and find that a market share of 14 per cent in Europe's life insurance companies would not survive an equity-stress test on the basis of Solvency I requirements, making the low-interest environment a critical strategic risk for this industry. Niedrig (2015) adds that, with life insurers being the largest buyers of bank bonds in Europe, this might also expose the banking sector to a funding risk. Generally, life insurances depict a widely researched industry segment, because their investment strategy is largely based on fixed income and therefore, subject to the changes in interest levels, as pointed out by Berends et al. (2013).

Other studies on the low-interest environment focus asset classes such as corporate debt in Barry et al. (2008), although real estate has been widely underresearched in this context until a short time ago. Specifically, Assenmacher-Wesche and Gerlach (2008) assumed the price development of residential properties to be an impulse for further economic impacts; they found evidence that shocks to these prices have a significant and positive effect on both GDP and credit. Belke et al. (2008) compared several OECD countries in terms of house price reactions as well as consumer price reactions towards changing monetary conditions. These authors identified a higher time lag for global consumer prices than for global house prices

and conclude that growth in liquidity is a valid indicator for house price inflation. Demary (2008) confirmed the real interest level, together with the GDP, as the most important impact factors for property prices, while their impact weight differs throughout international comparisons. For instance, Berlemann and Freese (2010) argue that, for the specific case of Switzerland in the year 2010, commercial property prices showed no reaction towards a variation in the interest rate level. In a meta-study, Kuttner (2012) ultimately identified several reasons, how the interest rate does impact property prices, for instance due to changes in the willingness to take risks by investors or owners, but generally finds that the effect of the interest rate on house prices is rather moderate. On a more general level, both fundamental and contemporary literature has dealt with the question of how to observe and measure, and possibly forecast, real estate market cycles. In that context, Grebler and Burns (1982) uncovered six residential and four non-residential construction cycles in the USA between 1950 and 1978. Pritchett (1984) more fundamentally concluded that there are national real estate market cycles on segment levels. Wheaton (1987) estimated American office market cycles to comprise approximately 10-12 years on the basis of a ten cities estimation sample. Witten (1987) argued on a more granular level that every city has own property cycles with own durations and volatilities, as they all rely on their specific demand and supply dynamics. Grissom and DeLisle (1999) and Dokko et al. (1999) have confirmed that real estate cycles are not only observable and presentable by models, but also that there is a macro-economic linkage in property market cycles; Grissom and DeLisle (1999) additionally investigated whether exogenous shocks can be modelled in these cycles (as we do in this work). For instance, Arsenault et al. (2013) have elaborated how mortgage supply is a significant driver of property prices, but also how this relationship may be subject to the endogeneity problem. Exemplified by 28 different international office markets, Mueller and Peiser (2015) discuss real estate market cycles in terms of four typical phases. They find that, while occupancy rates and rental growth are indeed highly correlated, this correlation is subject to different local time lags.

Based on a rather mathematical methodology, Evans and Mueller (2013) propose the application of Markov probabilities in order to estimate the further movement of the market and thereby developed a profound forecasting technique for property markets. Another probability-based approach was illustrated by Krystalogianni et al. (2004), as they first estimated cycle turning points and then constructed probit models including economic indicators to estimate the probability of different development directions in capital values. D'Amato (2015) contrasts the perspective of real estate cycles with the methods of property valuation, which are to a certain extent rather based on the assumption of at least stable income

fundamentals and suggests that these stable valuations may contribute to real estate bubbles as actual cycles are underestimated. As a specific driver of cycle characteristics, Zhang et al. (2015) have identified the role of governmental intervention in China on real estate markets and found that this has made volatility more evident in the market and changed the duration and frequency of China's property cycles. From a European perspective, Hartmann (2015) reflects the impact of borrower-based regulatory policies on financing, such as the forced reduction of debt portions, on the avoidance or smoothing of real estate booms; however, especially the European regulation is described as un-effective in terms of considering the continent's granular geographic and market structures in its policies.

2.3. Market observations against a sustainable reaction to interest rate changes

Most of Germany's top locations currently feature a situation, where "property prices are defined by the amount of capital that one can find, not value" (PricewaterhouseCoopers, 2015). This is backed by several observations from the market that are outlined in the following and of which the second one will be analysed according to in-depth econometric analysis afterwards.

2.3.1. The rental market and the investment market have decoupled

Like in many metropolitans worldwide, market players identify prices of German properties drifting apart from the rental market. The Figure 2 illustrates how this is reflected specifically for office markets in Germany. With both indices being re-based to the year 2003, the large discrepancy in rental prices and capital values become comparable and obvious (Figure 3).

2.3.2. The correlation pattern differs throughout the market phases

A visual analysis of the index for office capital values as well as the underlying ECB prime rate gives first insights into different direction and strength of association between both time series. While this is also backed by measuring simple correlation coefficients, this measurement does not yet take into account fundamental econometric considerations such as spurious correlation, auto-correlation or the time lag that applies when looking at transaction-based capital values and the interest rate due to longer term and differing holding periods between the several properties in the index. However, a simple correlation analysis already unveils that

the co-movements are – even in terms of their direction – widely different between the market phases (Figure 4). While for the time period between 2003 and the Lehman breakdown in 2008, there appeared to be an almost synchronistic co-movement of both interest level and office values, the correlation between these factors turned from strictly positive to strictly negative after this point, as illustrated in Table I. In addition to the simple correlation, we test according to Chow (1960) in order to econometrically control for structural breaks that we assume to be on hand in the given data before the first quarter of 2009. Please refer to Table AI for further insights.

2.3.3. Although widely interconnected, the development of property prices should be rather explained by economic fundamentals than pure interest effects

One could expect that – especially during the current low-interest phase – office performance is largely driven and reinforced by changes in interest rates contrary to the typical long-term expectation of being rather influenced by fundamentals of the real-economic environment. However, we argue that the positive correlation of interest rates and office performance of the pre-Lehman era is an indicator for the abrogation of the classical negative interaction of interest rates and property performance. Therefore, we focus on this third postulated hypothesis and further investigate it in the following. After a review of related literature, the empirical part of this work will analyse the reaction mechanisms between positive shocks in exogenous macroeconomic factors and the performance of office properties in terms of capital values and rents. Not only do we work out the strength and direction of respective impacts, but we also add the time perspectives as observable for Germany within the consideration horizon.

Figure 2.3: Capital values and rental price index for office properties

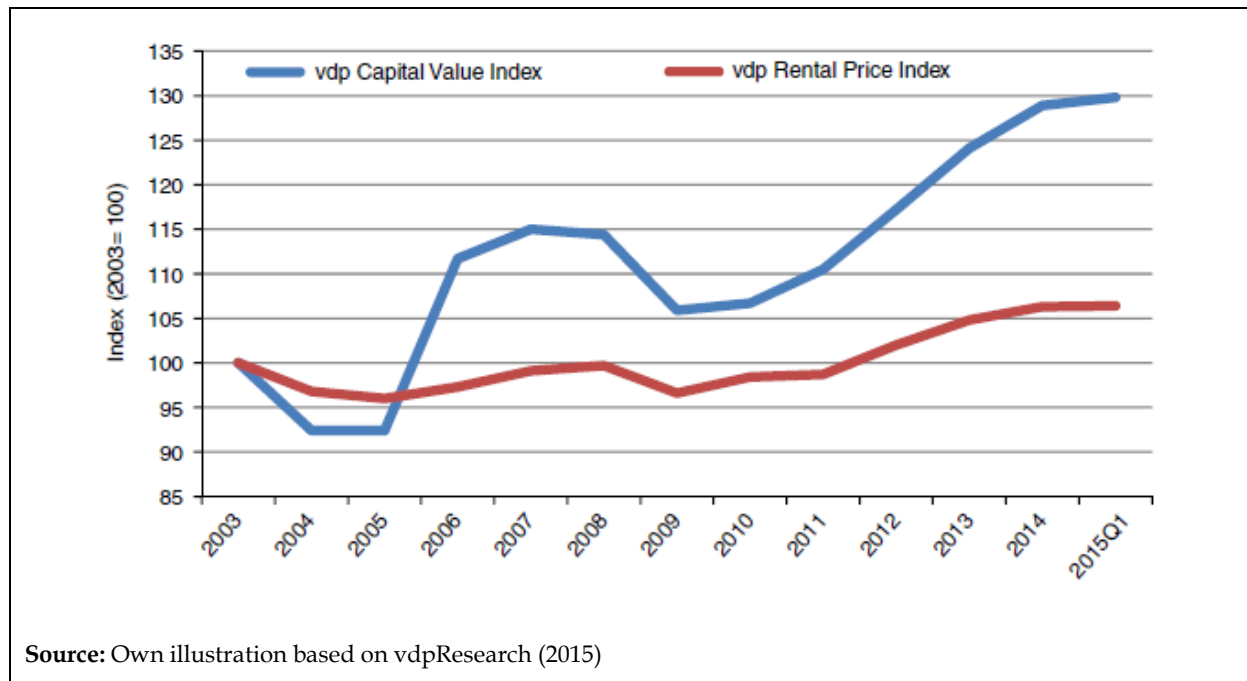


Figure 2.4: The development of office capital values (green) and the European prime interest rate (grey)

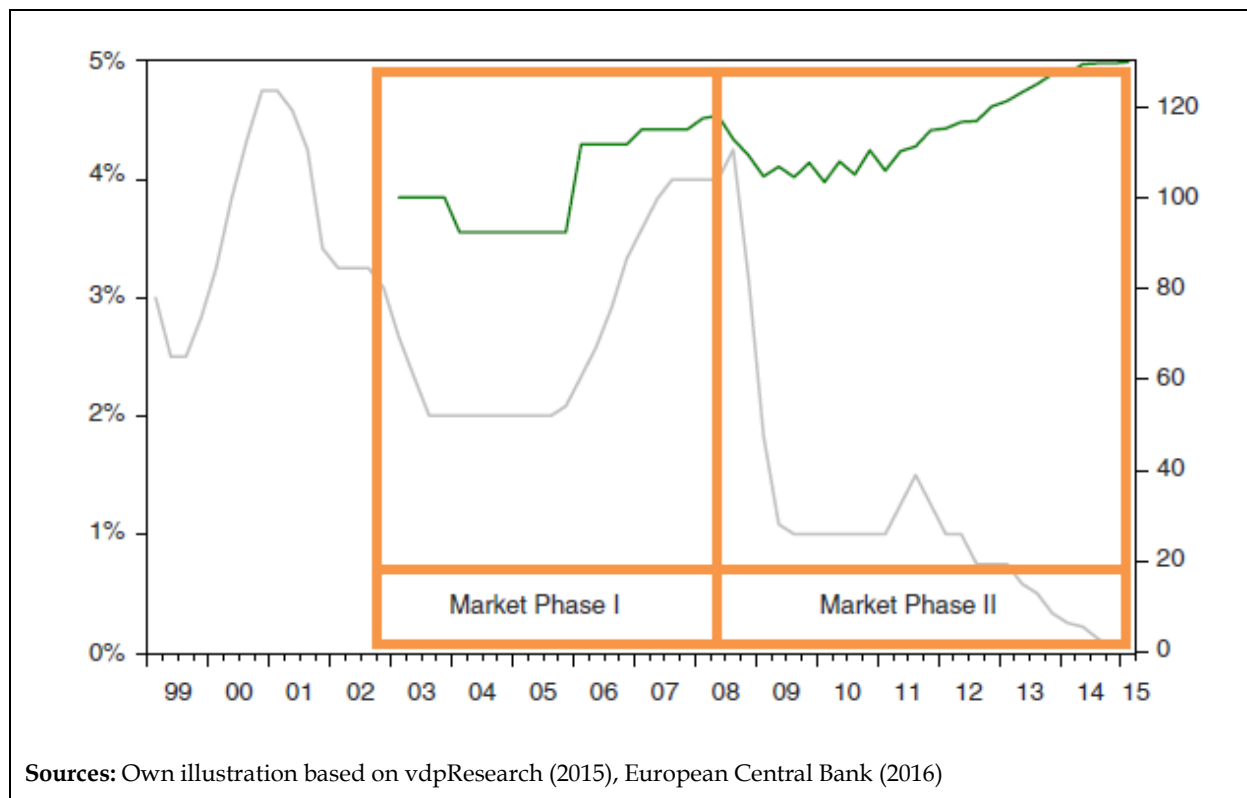


Table 2.1: Simple correlation factors in different market phases

Market phase	Correlation factor
I – 1/2003-12/2008 (“Pre-Lehman”)	+0.8427
II – 1/2009-2/2015 (“Post-Lehman”)	–0.8553
Note: Changing correlation factors in co-movement of interest level and office values own calculation	

2.4. Empirical analysis – impulses and reactions of the German office market

2.4.1. Data

This analysis is based on quarterly data covering the time frame between Q1/2003 and Q1/2015 and therefore, contains the low-interest phase.⁴ All selected macroeconomic indicators are part of the economic and monetary analysis framework of the European Central Bank on assessing risks and price stability and form the basis for monetary policy measures. The indicators included are real GDP growth for the reflection of the general economic development in Germany, the consumer price index as an indicator for inflation, the ECB prime rate in the form of the principal refinancing rate, the nominal return of the current ten years government bond, the nominal mortgage credit volume as well as the growth rate in money supply M3 on European level. Except for the government bonds as well as the prime rate, seasonally adjusted data were used or created in order to point out the factual trends in economic development.⁵

In terms of measuring real estate performance, we analyse data on rental prices as well as the property’s capital value as the two constituents of the total return (Geltner et al., 2007) (Table II). The vdp property price index is a composite indicator that reflects the development in different segments comprising residential and commercial real estate. Amongst other time series available, the specific capital value index for office properties measures the development of office values in Germany on the basis of rental data as well as current market cap rates. All original indices are calculated on the basis of hedonic methodology by vdpResearch. This approach is common with regard to price changes of heterogenous goods that show large differences in terms of their quality and characteristics, so that traditional approaches of price measuring are not adequate. The calculation explicitly incorporates existing differences in

⁴ The most current developments were also analysed in separate estimations that comprised Q2 and Q3, 2015, additionally. The analysis confirmed the validity of the estimated model, however, at a higher order of integration.

⁵ Where such data were not available, the seasonal adjustment was performed using the Census X-12 program.

fundamental property characteristics such as the size, age or location. According to information of the index provider, they reflect almost 90 per cent of all transactions on German property markets (vdpResearch, 2015).

2.4.2. Descriptive data analysis

In order to account for possible multicollinearity, we analysed the bilateral correlation coefficients as shown in the Table III. In research practice, a correlation value of 0.8 or more is frequently considered critical for impact on analysis and possible bias. Referring to correlation patterns, it becomes obvious that there is an expectable, discrete transgression of the threshold between consumer prices and the government bond yield (at -0.87), between money supply and the interest rate (at 0.85) as well as between the prime rate and the government bond yields (0.84). We understand this as evidence that the attribute of multicollinearity is immanent in many macro-economic time series, because the included factors often follow similar development patterns or trajectories resulting from the economy as a whole (Jaeger and Voigtlaender, 2007). We interpret this as justification for using the following methodology of vector-autoregressive models because this can better reflect the interplay of several macro-economic determinants that may be dependent and linked instead of purely analysing effects between exogenous and endogenous perspectives. Also, the presence of multicollinearity will not automatically harm the expressiveness of our coefficients and their development over time, as the model can still deliver an unbiased estimation with multicollinearity on hand.

Table 2.2: Overview of model parameters and data sources

Variable	Content	Source
GDP	Growth rates of real gross domestic product in %	OECD
LOG(CPI)	Consumer price index (2003 = 100)	Bundesbank
RATE	ECB prime rate in %	Bundesbank
GBOND	10 years government bond rate in %	OECD
M3	Growth rates of money supply in M3 in %	ECB
LOG(LOAN)	Nominal volume of mortgage loans to enterprises and individual households	Bundesbank
LOG(VALUE)	Index of the capital value (2003 = 100)	VDP
LOG(RENTS)	Index of rental prices (2003 = 100)	VDP

Table 2.3: Correlation matrix of all variables in both models

	GDP	CPI_2003	M3	LOAN_SA	GBOND	RATE
GDP	1.000000					
CPI_2003	0.058535	1.000000				
M3	0.103743	-0.626713	1.000000			
LOAN_SA	0.262899	0.709698	-0.206285	1.000000		
GBOND	0.001660	-0.871034	0.634698	-0.593930	1.000000	
RATE	0.153752	-0.651613	0.851634	-0.329840	0.840147	1.000000

2.4.3. Methodology

Vector-autoregressive (VAR) models were developed in 1980 by Sims as a widespread concept for analysing multivariate time series. The approach is specifically established for investigating the dynamic relations between several different economic time series. Contrary to regression models (VAR) models make no difference between endogenous and exogenous variables. Instead, all the parameters are considered in the model with special focus on temporal lags.

VAR(p) models are based on a vector $\gamma_t = (\gamma_{1t}, \dots, \gamma_{Kt})'$ with K time series variables, which is defined as the sum of a deterministic term μ_t and a purely stochastic process x_t , where μ_t depicts a linear trend as $\mu_t = \mu_0 + \mu_1 t$ and equals either 0 or the constant μ_0 and where x_t describes a VAR process of p^{th} order described as follows.

Formula 2.1: VAR process of p^{th} order

$$x_t = A_1 x_{t-1} + \dots + A_p x_{t-p} + u_t,$$

with A_i ($i = 1, \dots, p$) being ($K \times K$) parameter matrices as well as a K-dimensional error process $u_t = u_{1t}, \dots, u_{Kt}$, characterized by the attributes of a white noise. (Luetkepohl, 2011)

Formula 2.2: Attributes of the error process u_t

$$E(u_t u_t') = \Sigma_u \quad E(u_t u_s') = 0 \quad E(u_t) = 0$$

In addition, x_t determines d as the order of integration as well as possible cointegration relations. By using the lag operator $A(L)$ with the matrix polynomial $A(L) = I_K - A_1L - \dots - A_pL^p$, formula 2.1 can be transferred into a more consolidated form. (Luetkepohl, 2011)

Formula 2.3: Consolidated form of a VAR(p) process

$$A(L)x_t = u_t$$

By multiplying the stochastic process with $A(L)$ it becomes obvious that y_t follows a VAR process as follows.

Formula 2.4: Reduced form of a VAR(p) process

$$A(L)y_t = A(L)\mu_t + u_t \text{ or}$$

$$y_t = v_0 + v_1t + A_1y_{t-1} + \dots + A_py_{t-p} + u_t,$$

if $\mu_t = \mu_0 + \mu_1t$, $v_0 = (I_K - \sum_{j=1}^p A_j)\mu_0 + (\sum_{j=1}^p A_j)\mu_1$ and
 $v_1 = (I_K - \sum_{j=1}^p A_j)\mu_1$. (Luetkepohl, 2009)

The VAR process is stable if all roots are located outside the unit circle respectively if all Eigenvalues of $A(z)$ amount to less than one. As mean, variance and co-variance of x_t are time-invariant, this implies that the VAR process is stationary. (Luetkepohl, 2011) Given a stationary process, the reduced form of a VAR(p) process as in formula 2.4 can be represented as a Vector Moving Average or so-called Wold representation:

Formula 2.5: Wold representation of a VAR(p) process

$$y_t = A(L)^{-1}u_t = \phi(L)u_t = \sum_{j=0}^{\infty} \phi_j u_{t-j},$$

with $\phi(L) = \sum_{j=0}^{\infty} \phi_j L^j = A(L)^{-1}$ and ϕ_j as $(K \times K)$ coefficient matrices being defined as follows.

Formula 2.6: Coefficient matrices Φ_i .

$$\phi_i = \sum_{j=1}^i \phi_{i-j} A_j \quad i = 1, 2, \dots$$

In a VAR(p) model, the fundamental equations can be estimated using the method of Ordinary Least Squares (OLS), with an estimator being defined as follows.

Formula 2.7: Ordinary Least Squares Estimator

$$[\hat{v}_0, \hat{v}_1, \hat{A}_1, \dots, \hat{A}_p] = \left(\sum_{t=1}^T \gamma_t Z'_{t-1} \right) \left(\sum_{t=1}^T Z_t Z'_{t-1} \right)^{-1}$$

For the detection and interpretation of unexpected shocks within a variable and their impacts on the underlying VAR model, we apply impulse-response functions. The $(n,m)^{\text{th}}$ element of matrix ϕ_j as a function of j indicates, what impact an exogenous shock in $\gamma_{m,t}$ amounting to one standard deviation in time t has on the variable $\gamma_{n,t+j}$ at the time $t+j$.

In this context, the elements of ϕ_j represent the reactions to a certain shock u_t shock. (Luetkepohl, 2011) As there is a contemporary correlation between the residuals u_t and therefore an isolated effect of the shock is not unambiguously interpretable in an economic sense, orthogonal transformation of the error terms must be applied. This orthogonalization is based on the so-called Cholesky decomposition, where the covariance matrix of residuals u_t can be decomposed by a regular lower triangular matrix P of the equation

Formula 2.8: Regular lower triangular matrix

$$\Sigma_u = PP',$$

and thereby orthogonalized shocks can be defined in the form $\varepsilon_t = P^{-1}u_t$. In this format, the transformed shocks are characterized by $\varepsilon_t \sim (0, I_K)$ and therefore contemporarily uncorrelated, which enables the unambiguous attribution of a shock to a certain variable. (Luetkepohl, 2009)

In this format it is possible to measure the reaction to shocks through the moving average (MA) representation of an VAR(p) process as follows.

Formula 2.9: MA process with orthogonalized error terms.

$$\gamma_t = \sum_{j=1}^{\infty} \phi_j P P^{-1} u_{t-j} = \sum_{j=1}^{\infty} \psi_j \varepsilon_{t-j}$$

Where the matrices $\psi_j = \phi_j P$ contain the impulse-responses of the model-integrated variables to exogenous shocks. (Luetkepohl, 2009) By that means, the VAR model can project a variable's reaction to an exogenous shock over time from the perspective of $t = 0$.

For our specific model setup, the Cholesky decomposition implies that within the VAR(p) models the order of the variables cannot be arbitrary. The first variable of the model contemporarily influences all sub-ordered variables in the model, while the last variable of the model influences only itself. In that sense, the first variable is impacted by own shocks, the second element by own shocks and shocks from the first variable etc. (Belke et al., 2008).

In the theoretical framework of perfect competition, we would assume that the market does not show any delay in adapting to exogenous shocks such as the instant and significant change in interest rates. Due to the specific characteristics of real estate, however, property markets vary from this ideal and react with delay to unexpected, exogenous developments. As the performance-related data in this study represent transaction-based information, a time lag needs to be taken into account, as especially performance changes in terms of capital values are not becoming obvious before the next sale. Also, the transaction-based index considers both very liquid and less liquid properties, but the averaging of all properties leads to a discrepancy in reaction times. If we could suppose that all considered properties show the same liquidity, the same marketability and time-to-market, the market would show less delay, as all price changes would influence the index one-to-one. As actually less liquid properties are, however, typically not sold at the speed, their price development can only be foreseen way later than the development of liquid properties (Geltner et al., 2007).

We analyse the effect on office properties in terms of the prime interest rate, but also various other macro-economic drivers. With real estate being one of the largest industries in the German economy, it is subject to the status of these fundamentals, including the cyclical

economic dynamics such as economic growth, inflation in terms of consumer prices (which are frequently linked to increases in office rents in the context of long-term contracts), German long-term government bonds as direct competitors of prime property investments (Schaetz and Sebastian, 2009). In addition, we account for credit availability as properties are a typically rather loan-intensive asset class and the volume of credit is, therefore, an indication of the office investment demand. We also consider the growth rate of money supply because it indicates the future and long-term price development expectation of the central bank (Deutsche Bundesbank, 2012).

In order to avoid model misspecification due to a timely inconsistent model structure, a unit root test was performed. By that means, all variables were tested for stationarity according to the augmented Dickey Fuller test, integration the lag value p on the basis of the Schwarz criterion as well as automated calculation of the maximum number of possible lags (Table IV).

As only the parameters of GDP and credit volume showed stationarity in the first place on 5 per cent significance level, we re-ran the augmented Dickey Fuller test on the basis of first difference level in the time series. As results show, all variables are stationary on 5 per cent significance level, except for the growth in money supply which is integrated on 10 per cent significance level. Even if we would include trend considerations in the equation, all variables except for growth in money supply would stay stationary on 5 per cent level (M3 growth, however, would not stay stationary at 10 per cent level any more) (Table V).

Table 2.4: Augmented Dickey Fuller test – level values

Method	Statistic	Prob. ^a		
ADF – Fisher χ^2	31.0305	0.0133		
ADF – Choi Z-stat	-2.04692	0.0203		
<i>Intermediate ADF test results model parameters</i>				
Series	Prob.	Lag	Max lag	Obs
GDP	0.0523	1	10	47
CPI	0.6205	1	10	47
GBOND	0.8654	2	10	46
RATE	0.0157	1	10	63
M3	0.1203	3	10	45
LOAN	0.0149	0	10	48
VALUE	0.5363	0	10	48
RENTS	0.4324	0	10	48
Notes: ^a Probabilities for Fisher tests are computed using an asymptotic χ^2 distribution. All other tests assume asymptotic normality				

Table 2.5: Augmented Dickey Fuller test – first differences

Method	Statistic	Prob. ^a		
ADF – Fisher χ^2	123.943	0.0000		
ADF – Choi Z-stat	-8.62937	0.0000		
<i>Intermediate ADF test results D(model parameters)</i>				
Series	Prob.	Lag	Max lag	Obs
D(GDP)	0.0179	0	10	47
D(CPI)	0.0063	0	10	47
D(GBOND)	0.0000	1	10	46
D(RATE)	0.0196	0	10	63
D(M3)	0.3543	1	10	46
D(LOAN)	0.0000	0	10	47
D(VALUE)	0.0000	0	10	47
D(RENTS)	0.0000	1	10	46
Notes: ^a Probabilities for Fisher tests are computed using an asymptotic χ^2 distribution. All other tests assume asymptotic normality				

Estimating VAR equations with non-stationary variables would typically lead to spurious correlations. Including difference levels of non-stationary variables is discussed because through such model, the information on the long-term behaviour of the variables, which is contained in level values, gets lost. However, following the fundamental argumentation of Sims et al. (1990), VAR models with non-stationary variables still lead to consistent OLS estimations, if at least two of the involved variables are first-order integrated and cointegrated, i.e. related in such a way that deviations from this relation again are a stationary process (Phillips and Durlauf, 1986). That is why we additionally performed a cointegration analysis of both models following the approach of Johansen, which delivers that in a system of all active model parameters, at least two cointegration relations are on hand independent of any assumption on trend or intercept. Therefore, we estimate the VAR(p) models on the basis of level values (Table VI). Also, we investigate the stability of our VAR(p) models by utilizing the inverse roots approach regarding the characteristic AR polynomial in accordance with Luetkepohl (1991). We find that both models show root values of less than one and all roots lie within the unit circle as illustrated in the Figures 5 and 6, therefore fulfilling the stability requirements.

Table 2.6: Results of the Johansen system cointegration test

Selected (0.05 level ^a) number of cointegrating relations by model				
Data Trend	None	None	Linear	Linear
Test type	No intercept	Intercept	Intercept	Intercept
	No trend	No trend	No trend	Trend
Trace	5	6	5	6
Max-eig	2	3	3	3
Source: ^a Critical values based on McKinnon <i>et al.</i> (1999)				

Source: aCritical values based on McKinnon et al. (1999)

Figure 2.5: Unit root graph for the VAR capital value model

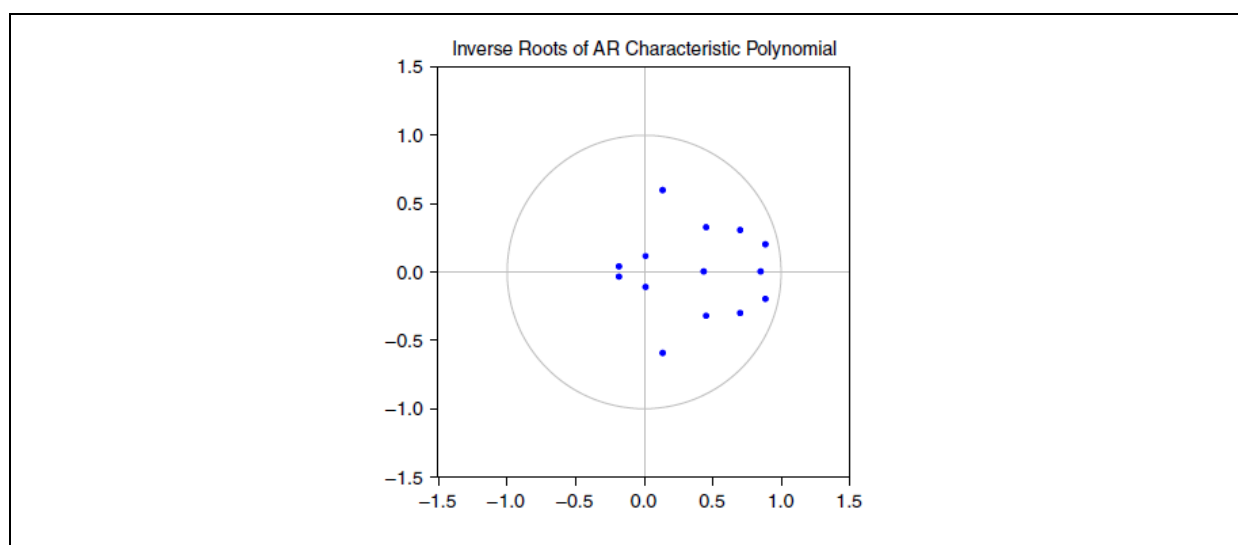
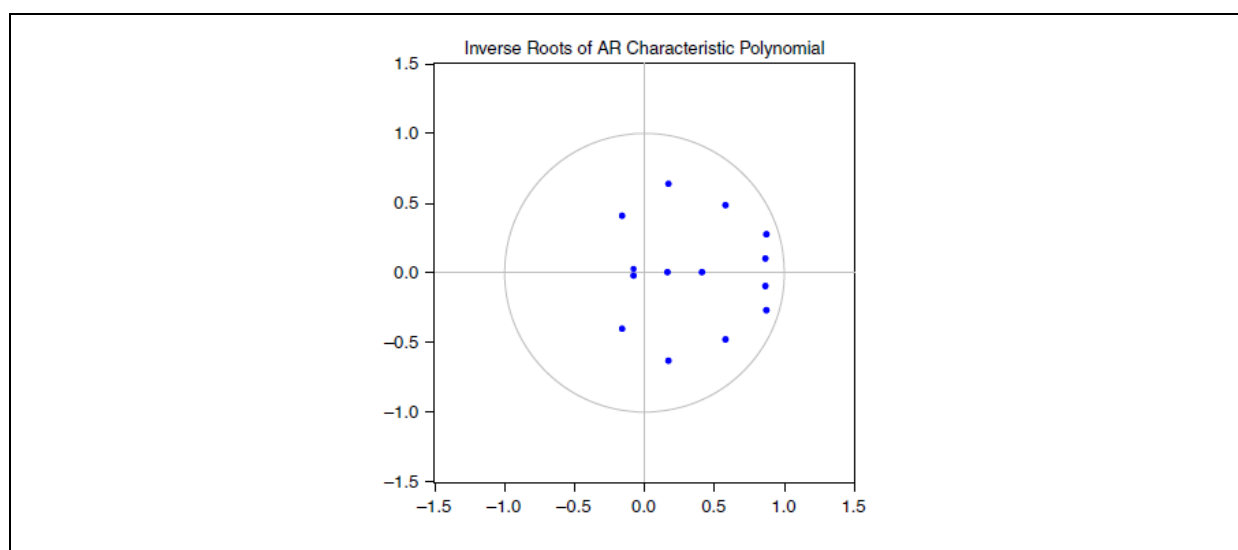


Figure 2.6: Unit root graph for the VAR rental price model



In addition to stability, we analyse all variables for Granger causality. A variable y_1 is Granger-causal to a second variable y_2 , if adding past values of y_1 improves the explanatory power of y_2 (Dreger et al., 2014). While this frequently changes significant variables into insignificant in terms of the feedback relations in the model, as soon as the model becomes more than bivariate, and is therefore perceived controversially amongst researchers, we assume that:

- (1) it is closer to reality to account for more influencing factors than only the interest rate level; and
- (2) the approach of Granger causality gives at least a profound indication on differences in causality when considering a whole set of economic drivers in addition to interest levels amongst the two models that we construct.

Both models that we construct are also checked for auto-correlation in residuals, heteroscedasticity, and normal distribution. Using impulse-response functions, we are able to perform an isolated analysis on which impact a single one-time exogenous shock in one of the VAR model variables has on its own development as well as on the other parameters. (Dreger et al., 2014) For the recognition and interpretation of the dynamic relationships between the diverse macro-economic variables and the fundamental property performance indicators, we perform a generalized impulse-response analysis according to Pesaran and Shin (1998), where the chronology of variables is irrelevant, covering a time frame of 24 quarters. In this context, we illustrate in the following the functional impact chain of a positive shock amounting to one standard deviation on the initial yields, the capital values as well as the rental prices.

In addition, we check the models according to our insights into structural breaks within the time series. Through applying the Chow test, we analyse whether the regression coefficient shows continuity and consistency within sub-terms of the whole time series. After validation of the structural breaks, we integrate dummy variables for both time frames and check their significance according to t test. Also, the residuals of both models are investigated in order to find out whether this distinction has had any impact on the error terms and therefore the goodness of the models.

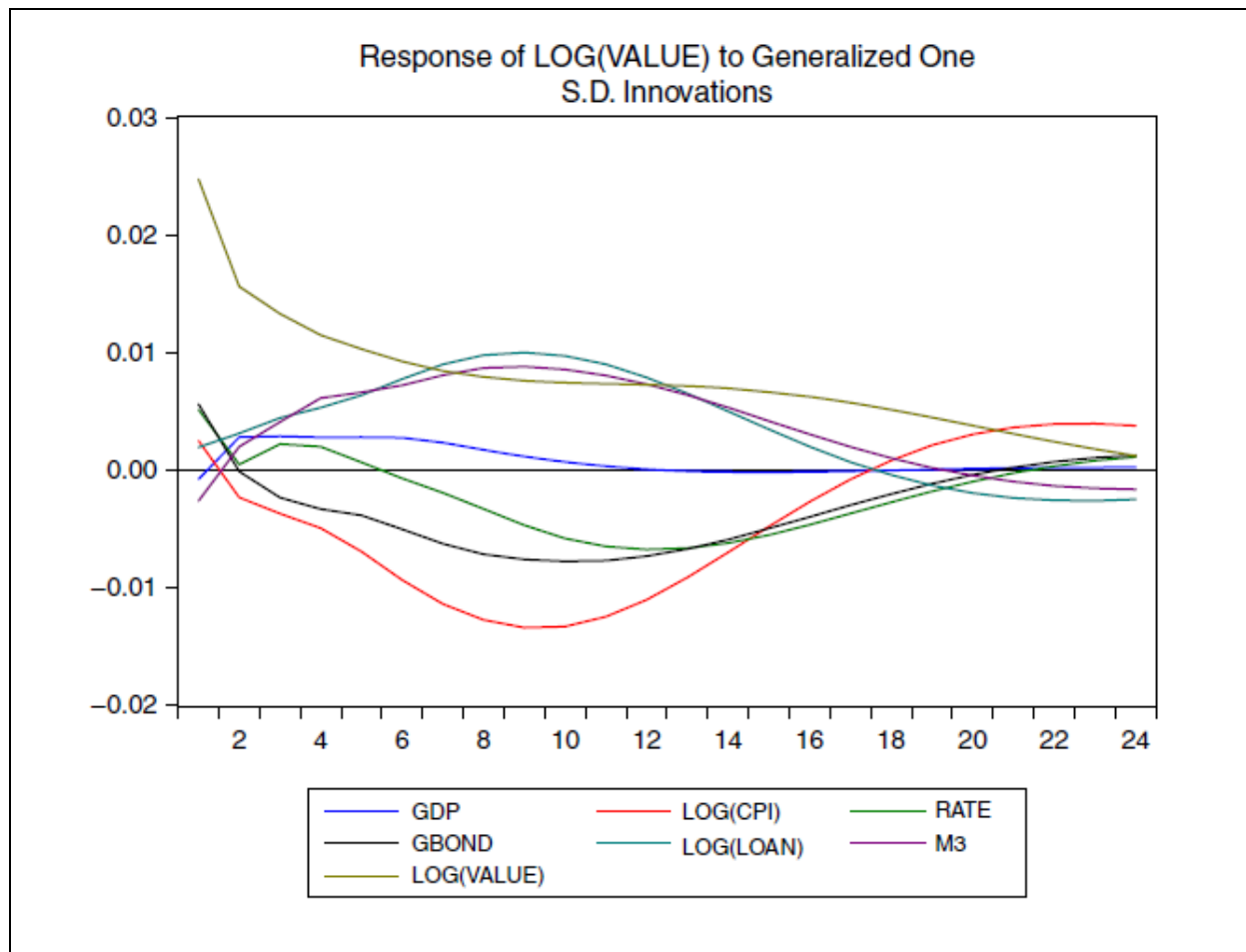
As we need to integrate the time lag issue in the model, we need to determine a lag order that we suppose for testing. This determination is based on the information criteria of Akaike, Hannan-Quinn as well as Schwarz and the sequentially modified test statistic of the Likelihood ratio. For calculating the lag length, a maximum of delay intervals needs to be defined

beforehand. In the context of this analysis, a maximum length of four lags was assumed (Figures 7 and 8).

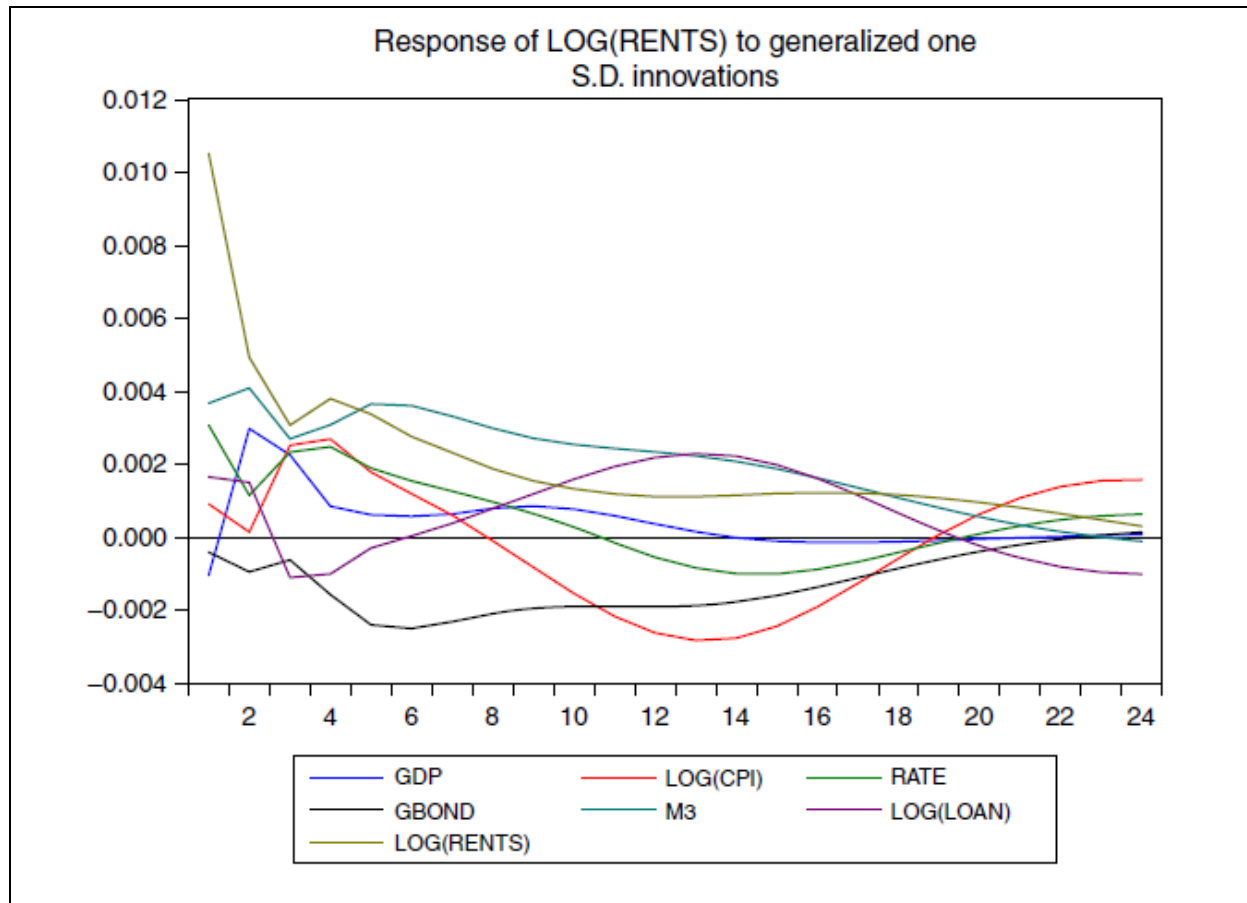
2.4.4. Empirical results

This study finds a high level of stability in office property values as a reaction to exogenous economic shocks with the general picture of coefficient impacts being rather close around the value base line. In terms of the impulse-response functions, we measure that – considering the whole period between 2003 and 2015 in the response simulation – a one standard deviation change in the GDP growth rate had only marginal effect at less than 1 per cent on the capital value change of office properties. This is interesting, because it contradicts the hypothesis that an economic upcycle automatically increases office prices and we had expected a stronger reaction.

Figure 2.7: Generalized impulse-response function in the VAR capital value model Q1/2003-Q1/2015



**Figure 2.8: Generalized impulse-response function in the VAR rent price model
Q1/2003-Q1/2015**



One possible explanation for this development could be that office values and the economic cycle were moving into one direction until mid of 2011. From this point in time on, however, we could see a divergence and therefore a decoupling of the price development from the general economic growth range. Contrary to that, we measure that the effect of an economic cycle shock influences rents strongly positive at the beginning, however, this effect alleviates relatively quickly. Generally, we observe that the rental market reacts a lot more sensitive to economic volatility than the investment market. This appears plausible, as companies are becoming very careful very quickly in times of high economic uncertainty and therefore, cut back their space demand and reduce renting faster than properties can be sold on the investment market. Also, asset managers may be tempted to hold the asset throughout times of economic uncertainty to avoid forced sales. An increase in consumer prices typically results in an increase of prime rates, which again leads to a generally higher interest level in terms of,

e.g. credit loan rates. This makes property investments relatively less attractive and will end up in decreasing capital values.

Regarding the impact of inflation on office rents, we confirm an effect, that is, positive at the beginning, however, converting to negative after approximately two years, and finally becoming positive again. The initially positive effect can be explained due to index rents for offices as well as an increasing demand on properties as inflation protection investments. However, as an increase in inflation rate, results in increasing interest rates, the initially price-increasing demand could drop again and cause the decrease of rents. In addition, the effect of rent increases is not sufficient to compensate the general inflation on the market.

In terms of capital values, the reaction to an unexpected prime rate and government bond yield change patterns slightly more distinct. A shock in government bond yields has quicker and more intensive impact than a shock in prime rates. This emphasizes the importance of return spreads between properties and government bonds as a benchmark for the attractiveness of a property investment. In general, the slightly delayed reaction of capital values to a prime rate shock can be an indication for adaption delay regarding suddenly occurring changes, which are intrinsic for real estate markets. The effect of an interest shock in terms of office rents is a priori positive and very rapid, although with less impact in comparison to capital values. This may be due to the fact that the development of new space requires certain time effort, and increased demand leads to higher property rents due to a temporary supply shortage. Overall, we would not have expected the specific development of property values after a prime rate shock, as a positive development is observed for another approximately six quarters, before the expected effect of decreasing property prices occurs. This can be explained, first, by the time lag that exists especially as we consider transaction-based prices and office properties are not typically re-sold again on quarterly bases. In addition, we find that the observation period between 2003 and 2015, which we base the analysis on, contains two specific market phases that may lead to forecasted patterns, where prices increase with increasing prime rates, as it happened especially between 2003 and 2008.

Regarding the response of office rents to a shock in government bonds, a positive effect would have been expected, as increasing government bond yields are also the result of an accelerating economic growth. One explanation for the negative effect that we measure could be that increasing government bond yields lead to decreasing demand for office properties, on the one hand due to higher attractiveness of investment alternatives, but on the other hand also

as indication for a higher interest level. The change in capital values is negative considering the positive effect of increasing government bond yields.

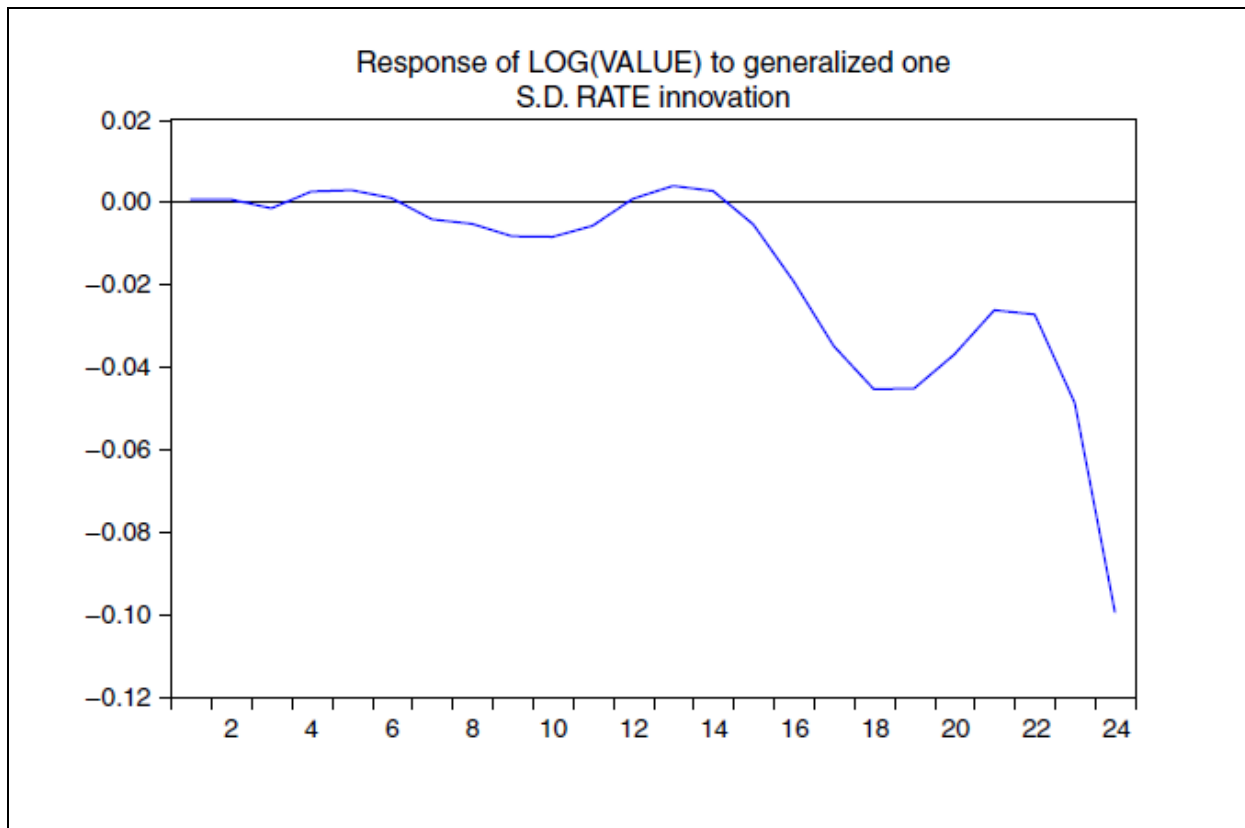
Both property performance indicators show a positive response to a shock in mortgage loan volume as well as in money supply growth. As offices are a very capital-intensive asset class, the availability of liquidity on the market is crucial for investments. One reason for the reluctance on the commercial real estate market after outburst of the economic crisis was the restricted practice in bank lending. In addition, money supply M3 reflects – contrary to the mortgage loan volume, which shows purely the German perspective – capital flows in all Euro markets. Furthermore, the largest response is tracked in the case of an internal shock amongst both performance indicators. This illustrates that especially changes in the office market itself impact the property performance.⁶

We additionally performed a specific analysis in terms of the low-interest phase. That means, we calculate the estimations separately on the basis of data from 2009 to 2015 only. In this sub-sample, a shock in the prime rate shows – as illustrated in Figure 9 – rather stable and more rapidly negative effect on the capital value change of the office property. Even on the basis of that sub-sample, negative effects occur with a time lag of approximately six quarters on the transaction market and recover between quarter 12 and 15. After that time, the expected negative development of a shock in interest rates is estimated.

We derive from this that increasing financing costs in the context of a possible interest leap would stress the office performance less than expected initially. At the level of total return, increasing capital value and rental growth lead add up to an improvement of the overall performance. The null hypothesis of “no structural break” can be rejected in terms of the capital values, so that a structural break in the data can be assumed (please see, Table AI for output details). As we identified at least two different market phases, we added dummy variables in order to account for differences in the patterns between both phases. A t test delivers the significance of this dummy variable when controlling the overall model of capital values as well as the specific single equation for credit lending volume. This confirms our assumption that making a difference between the two market phases and the related observations is important. What is interesting about this distinction is that integrating the dummy variable does reduce the variations in error terms and thereby reduces the standard deviation. This leads to an improvement of the model (see, Figure A3 for variance details).

⁶ Figure A1 provides detailed graphs on the particular variables included in the rental price model. Figure A2 provides the same, more detailed insights into the capital value model.

Figure 2.9: Generalized prime rate impulse-response function in the VAR capital value model 2009-2015



Regarding the impact causality of the selected macro-economic criteria, we find that the null hypothesis of a lacking causality cannot be rejected on a 5 or 10 per cent level regarding the initial yield, capital values as well as rent prices, so that a feedback relationship in terms of Granger causality cannot be observed. Contrary to that, however, the property return shows a Granger-causal relationship to GDP growth as well as government bond yields on a 5 per cent level. Also, Granger causality can be identified between the initial yield and the prime interest rate on a 10 per cent significance level. Also, while no Granger causality can be identified regarding the time series of the capital value index, the rental prices show Granger causality to the prime rate on a 5 per cent level. For the purpose of completeness it should be noted that the concept of Granger causality is not undisputed in practice, because in models with more than two considered variables the interaction of causalities becomes more and more complex. That becomes apparent in constellations where bivariate models show causal relationships between two times series, while they lose significance after adding additional parameters (Luetkepohl, 2011).

2.5. Summary and outlook

This study finds that the overall expected response to a positive impulse in several macro-economic determinants on the basis of development patterns from the past 12 years is very diverse; but especially for a change in the interest rate level, we identify that a further increase going forward may still cause slightly positive effects on office rents. At this point, impulse-response functions reveal a situation of true economic sustainability, as rents show a consistently and continuously positive expected development and response even towards a positive shock in interest level over the full estimation period of 24 quarters.

Also, the expected change in capital value can be considered to be probably positive at least for a certain period of time. On the basis of the integrated interest-related estimation parameter, we observe that a positive value effect is expectable for more than four years, even if the interest rate is subject to a shock increase. It is only in the long-run that office investments appear to follow the supposed negative correlation of interest rates and value impact.

Generally, we find that the impact of a positive shock of one standard deviation is rather low in absolute means, as change factors are – depending on the underlying time period – between minus 4 and 3 per cent in the rent model or even closer around 0 in the capital value model. However, we cannot confirm an instantly or straightly negative impact of a sudden change in interest rates, as would be suggested by the long-term relationship structures between interest rate and property values. In that sense, we find short-term reason to agree with Gibson's paradox of a positive correlation between interest rates and the price level. In terms of the office markets, we, therefore, expect adjusted investment patterns, where investors move their asset allocation away from value-driven investments to yield- and income-oriented investments.

2.5.1. Further research

With the broad international diversity of interest policies and development options, the given research field provides a variety of opportunities for further research. One possible direction could be the analysis of regional differences in impulse-response patterns, for example, between the USA with early stages of ascending interest levels and the Euro area, where interests are expected to be constant for the moment.

As a second direction, Japanese office markets could constitute an interesting research subject with its longer history in low-interest levels and vibrant office markets especially in larger cities. As a third research direction, we find that the analysis performed could also be done using vector error-correction models in order to gain insights into deviations from the long-term trend and to isolate the temporary patterns related to this. Impulses from interest changes could then be interpreted on the basis of differences towards the long-term trend. For ideal results, this would, however, require a longer term time series on office performance in Germany.

Also, the model could be additionally checked for the variance decomposition in order to identify the strength of all driving forces and their impact development over time. We assume that, in the beginning, shocks from fundamental factors such as the growth rates in GDP have a higher explanatory impact than, for instance, the money supply, but over time, these proportions do not stay constant.

2.5.2. Limitations

The main limitation of the study performed consists in the fact that the underlying data set contains two rather extraordinary market phases, namely the bubble development phase from 2003 to 2008 as well as its reaction, the low-interest phase. We find that certain patterns in both phases neutralize each other when looking at the total time frame. That is why the impulse-response on the basis of the opposed movements in the overall time series is significantly lower than when performing an isolated analysis on the basis of experiences from the low-interest phase. In this respect, it stays unclear to what extent the measured impulse-responses stay forecast-proof, if the market moves into a phase of short-term normalization coming out of the low-interest phase.

2.6. References

- Akram, T. and Das, A. (2014), "The determinants of long-term Japanese Government bonds' low nominal yields", Working Paper No. 818, Levy Economics Institute, Annandale-on-Hudson, New York, NY, October.
- Archer, W. and Ling, A. (1997), "The three dimensions of real estate markets: linking space, capital and property markets", *Real Estate Finance*, Vol. 14 No. 3, pp. 7-14.

- Arsenault, M., Clayton, J. and Peng, L. (2013), "Mortgage fund flows, capital appreciation and real estate cycles", *The Journal of Real Estate Finance and Economics*, Vol. 47 No. 2, pp. 243-265.
- Assenmacher-Wesche, K. and Gerlach, S. (2008), "Monetary policy, asset prices and macroeconomic conditions: a panel-VAR study", Working Paper No. 149, National Bank of Belgium, Brussels, October.
- Atisreal (2009), "Investment market report Germany 2009", available at: www.realestate.bnpparibas.de/upload/docs/application/andrew-inset/2014-10/2009_atisreal_investment_market_report_germany_2014-10-22_11-38-41_305.pdf (accessed 14 January 2016).
- Barry, C., Mann, S., Mihov, V. and Rodriguez, M. (2008), "Corporate debt issuance and the historical level of interest rates", *Financial Management*, Vol. 37 No. 3, pp. 413-430.
- Belke, A., Orth, W. and Setzer, R. (2008), "Global liquidity and house prices – a VAR analysis for OECD countries", Working Paper No. 08-02, ROME discussion paper series, Duesseldorf, May.
- Berends, K., McMenamin, R., Plestis, T. and Rosen, R. (2013), "The sensitivity of life insurance firms to interest rate changes", *Federal Reserve Bank of Chicago Economic Perspectives*, Vol. 37 No. 2, pp. 47-78.
- Berlemann, M. and Freese, J. (2010), "Monetary policy and real estate prices: a disaggregated analysis for Switzerland", Working Paper No. 2-19, Hamburg Institute of International Economics, Hamburg, 9 October.
- BNP Paribas Real Estate (2015a), "At a glance: office investment market Germany Q2", available at: www.realestate.bnpparibas.de/upload/docs/application/pdf/2015-07/2015-q2_bnppre_aag_office_investment_eng.pdf (accessed 14 January 2016).
- BNP Paribas Real Estate (2015b), "Investment market Germany: property report 2015", available at: www.realestate.bnpparibas.de/upload/docs/application/x-octetstream/2015-05/2015_bnppre_pr_investment_germany_eng.pdf (accessed 14 January 2016).
- Chow, G. (1960), "Tests of equality between sets of coefficients in two linear regressions", *Econometrica*, Vol. 28 No. 3, pp. 591-605.

- D'Amato, M. (2015), "Income approach and property market cycle", *International Journal of Strategic Property Management*, Vol. 19 No. 3, pp. 207-219.
- Demary, M. (2008), "The economic relevance of property price variance", *IW Trends – Quarterly Journal on Empirical Economic Research*, No. 4, pp. 1-14.
- Deutsche Bundesbank (2012), "Safeguarding stability – The Deutsche Bundesbank's responsibilities and activities", available at: www.bundesbank.de/Redaktion/EN/Downloads/Publications/Bundesbank/safeguarding_stability.pdf?__blob¼publicationFile (accessed 14 January 2016).
- Dokko, Y., Edelstein, R., Lacayo, A. and Lee, D. (1999), "Real estate income and value cycles: a model of market dynamics", *Journal of Real Estate Research*, Vol. 18 No. 1, pp. 69-96.
- Dreger, C., Kosfeld, R. and Eckey, H.-F. (2014), *Econometrics. Fundamentals – Methods – Examples*, 5th ed., Springer, Wiesbaden.
- European Central Bank (2009), "Conventional and unconventional monetary policy", available at: www.ecb.europa.eu/press/key/date/2009/html/sp090428.en.html (accessed 14 January 2016).
- European Central Bank (2016), "Key ECB interest rates", available at: www.ecb.europa.eu/stats/monetary/rates/html/index.en.html (accessed 14 January 2016).
- Evans, R. and Mueller, G. (2013), "Retail real estate cycles as Markov chains", *Journal of Real Estate Portfolio Management*, Vol. 19 No. 3, pp. 179-188.
- Fujiki, H. and Shioji, E. (2006), "Bank health concerns, low interest rates, and money demand: evidence from the public opinion survey on household financial assets and liabilities", *Monetary and Economic Studies*, Vol. 24 No. 2, pp. 73-124.
- Fujiki, H. and Shiratsuka, S. (2002), "Policy duration effect under the zero interest rate policy in 1999-2000: evidence from Japan's money market data", *Monetary and Economic Studies*, Vol. 20 No. 1, pp. 2-32.
- Geltner, D., Miller, N., Clayton, J. and Eichholtz, P. (Eds) (2007), *Commercial Real Estate Analysis & Investments*, 2nd ed., Thomson South-Western, Mason, OH.
- German Council of Economic Experts (2015), "Updated economic forecast for 2015", German Council of Economic Experts, Wiesbaden, 26 March.

- Grebler, L. and Burns, L. (1982), "Construction cycles in the United States since World War II", *Real Estate Economics*, Vol. 10 No. 2, pp. 123-151.
- Grissom, T. and DeLisle, J. (1999), "A multiplex index analysis of real estate cycles and structural change", *Journal of Real Estate Research*, Vol. 18 No. 1, pp. 97-129.
- Hartmann, P. (2015), "Real estate markets and macroprudential policy in Europe", *Journal of Money, Credit and Banking*, Vol. 47 No. S1, pp. 69-80.
- Jaeger, M. and Voigtlaender, M. (2007), "Determinants of office yields", *IW Trends*, Vol. 34 No. 4, pp. 1-14.
- JLL (2009), "Real estate investment markets trapped in the vortex of the financial market and economic crisis", available at: www.jll.de/Documents/JLL_Germany_Kurzkommentar_Investmentmarkt_Gewerbeimmobilien_Tabelle_Charts_2008_2009_1.pdf (accessed 14 January 2016).
- JLL (2015), "Investment Market Overview Germany, 2nd quarter 2015", JLL, Frankfurt.
- Just, T. (2010), "Internationalization of the German office market", *Information zur Raumentwicklung*, Nos 5/6, pp. 341-350.
- Kablau, A. and Weiss, M. (2014), "How is the low-interest-rate environment affecting the solvency of German life insurers?", *Discussion Papers No. 27*, Deutsche Bundesbank Research Centre, Frankfurt, 27 October.
- Keynes, J. (1930), *A Treatise on Money V1: Pure Theory of Money*, Macmillan, London.
- Krystalogianni, A., Matysiak, G. and Tsolacos, S. (2004), "Forecasting UK commercial real estate cycle phases with leading indicators: a probit approach", *Applied Economics*, Vol. 36 No. 20, pp. 2347-2356.
- Kuttner, K. (2012), "Low Interest rates and housing bubbles: still no smoking gun", Working Paper No. 2012-01, Williams College Department of Economics, Williamstown, pp. 1-27.
- Luetkepohl, H. (1991), *Introduction to Multiple Time Series Analysis*, Springer, Berlin.
- Luetkepohl, H. (2009), "Econometric analysis with vector autoregressive models", in Belsley, D. and Kontoghiorghes, E. (Eds), *Handbook of Computational Econometrics*, Wiley, Chichester, pp. 281-319.

- Luetkepohl, H. (2011), "Vector-autoregressive models", Working Paper No. 30, European University Institute, Department of Economics, Florence, 13 October.
- McKinnon, J., Haug, A. and Michelis, L. (1999), "Numerical distribution functions of likelihood ratio tests for cointegration", *Journal of Applied Econometrics*, Vol. 14 No. 5, pp. 563-577.
- Mueller, G. and Peiser, R. (2015), "International real estate office market cycles", *Real Estate Finance*, Vol. 31 No. 4, pp. 147-156.
- Niedrig, T. (2015), "Optimal asset allocation for interconnected life insurers in the low interest rate environment under solvency regulation", *Journal of Insurance Issues*, Vol. 38 No. 1, pp. 31-71.
- OECD (2015), "Monthly monetary and financial statistics (MEI): interest rates", available at: <http://stats.oecd.org/index.aspx?queryid=486> (accessed 14 January 2016).
- Pesaran, H. and Shin, Y. (1998), "Generalized impulse response analysis in linear multivariate models", *Economic Letters*, Vol. 58 No. 1, pp. 17-29.
- Phillips, P. and Durlauf, S. (1986), "Multiple time series regression with integrated processes", *Review of Economic Studies*, Vol. 53 No. 4, pp. 473-495.
- PricewaterhouseCoopers (2015), "Emerging trends in real estate Europe", available at: www.pwc.com/en_IM/IM/publications/assets/emerging-trends-in-real-estate-europe-2015.pdf (accessed 14 January 2016).
- Pritchett, C. (1984), "Forecasting the impact of real estate cycles on investment", *Real Estate Review*, Vol. 13 No. 4, pp. 85-89.
- Savills (2014), "Market report investment Germany", available at: savills.co.uk/germanyresearch/ger-ger-2014/investmentmarkt-deutschland-2014.pdf (accessed 14 January 2016).
- Schaetz, A. and Sebastian, S. (2009), "The links between property and the economy – evidence from the British and German markets", *Journal of Property Research*, Vol. 26 No. 2, pp. 71-191.
- Schaetz, A. and Sebastian, S. (2011), "Indirect real estate investments and their interrelation with direct investments – stock markets and the real economy – a VECM analysis", *Zeitschrift für Immobilienökonomie*, Vol. 10 No. 1, pp. 83-107.

- Shiller, R. (2007), "Low interest rates and high asset prices: an interpretation in terms of changing popular economic models", *Brookings Papers on Economic Activity*, No. 2, pp. 111-133.
- Sims, C., Stock, J. and Watson, M. (1990), "Inference in linear time series models with some unit roots", *Econometrica*, Vol. 58 No. 1, pp. 113-144.
- vdpResearch (2015), "vdp real estate price indices", available at: www.vdpresearch.de/vdpimmobilienpreisindizes/ (accessed 14 January 2016).
- Wheaton, W. (1987), "The cyclic behavior of the national office market", *Journal of the American Real Estate and Urban Economics Association*, Vol. 15 No. 4, pp. 281-299.
- Wicksell, K. (1907), "The influence of the rate of interest on prices", *The Economic Journal*, Vol. XVII, pp. 213-220.
- Witten, R. (1987), "Riding the real estate cycle", *Real Estate Today*, August, pp. 42-48.
- Zhang, H., Gao, S., Seiler, M. and Zhang, Y. (2015), "Identification of real estate cycles in China based on artificial neural networks", *Journal of Real Estate Literature*, Vol. 23 No. 1, pp. 65-84.

2.7. Annex

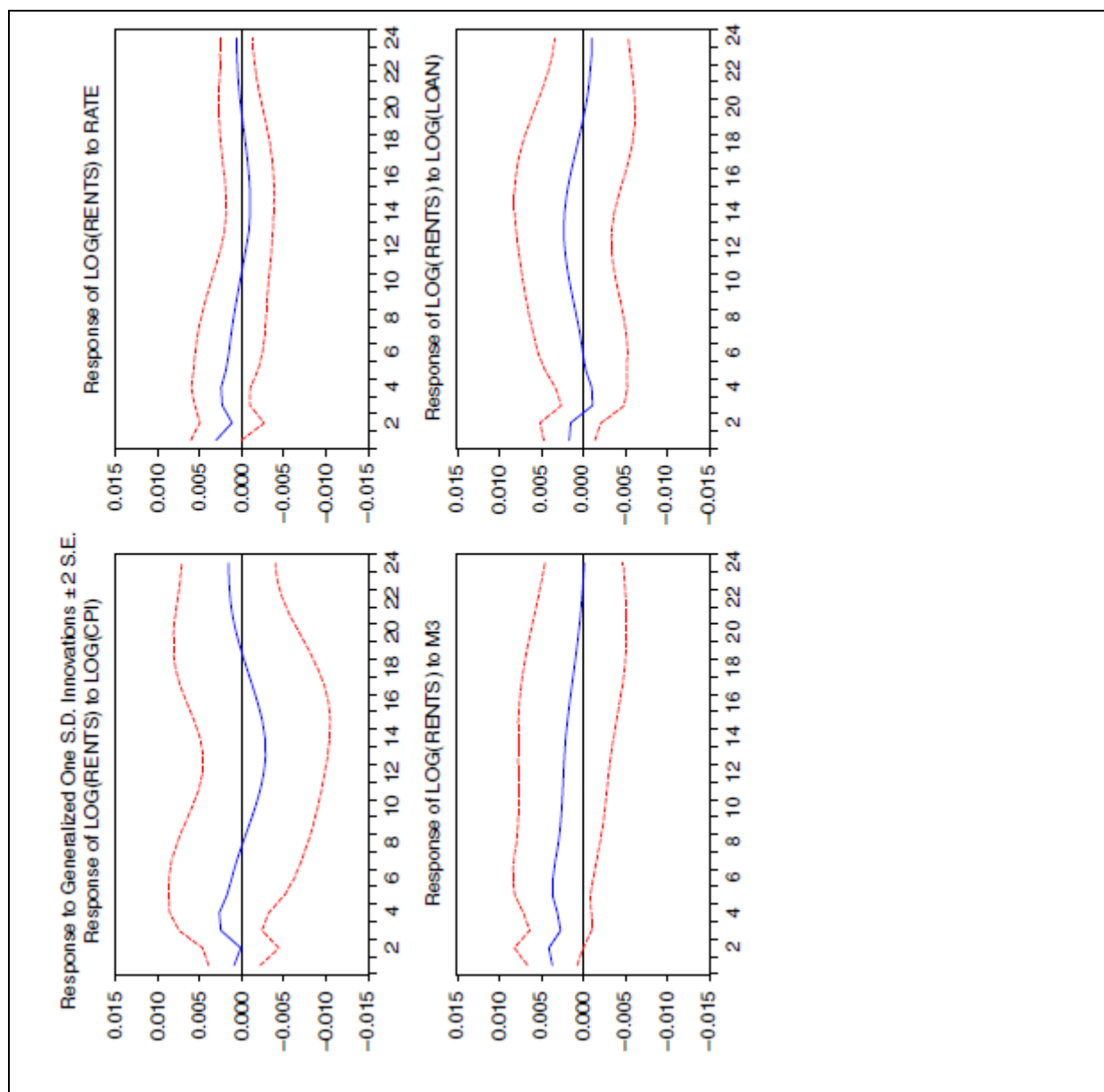
Appendix 1

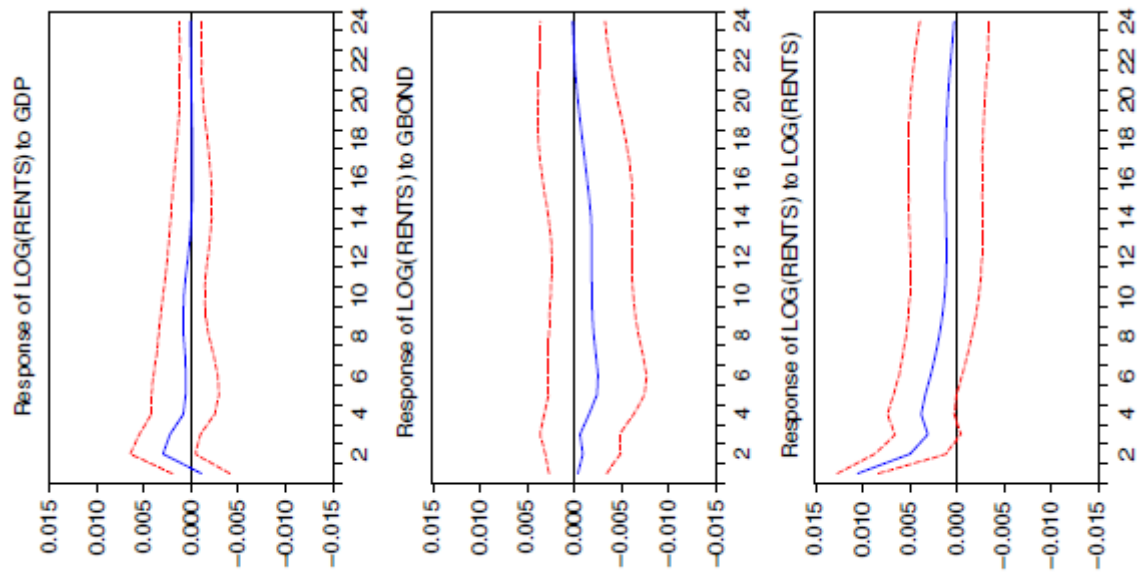
Table 2.A1: Equation outputs regarding Structural Breaks in the Data

Chow breakpoint test: 2009Q1			
Null hypothesis: no breaks at specified breakpoints			
Equation sample: Q1/2003-Q1/2015			
<i>Eviews output capital value breakpoint test</i>			
F-statistic	17.99394	Prob. $F(1,47)$	0.0001
Log likelihood ratio	15.88318	Prob. $\chi^2(1)$	0.0001
Wald statistic	17.99394	Prob. $\chi^2(1)$	0.0000
<i>Eviews output rental prices breakpoint test</i>			
F-statistic	14.01319	Prob. $F(1,47)$	0.0005
Log likelihood ratio	12.78618	Prob. $\chi^2(1)$	0.0003
Wald statistic	14.01319	Prob. $\chi^2(1)$	0.0002

Appendix 2

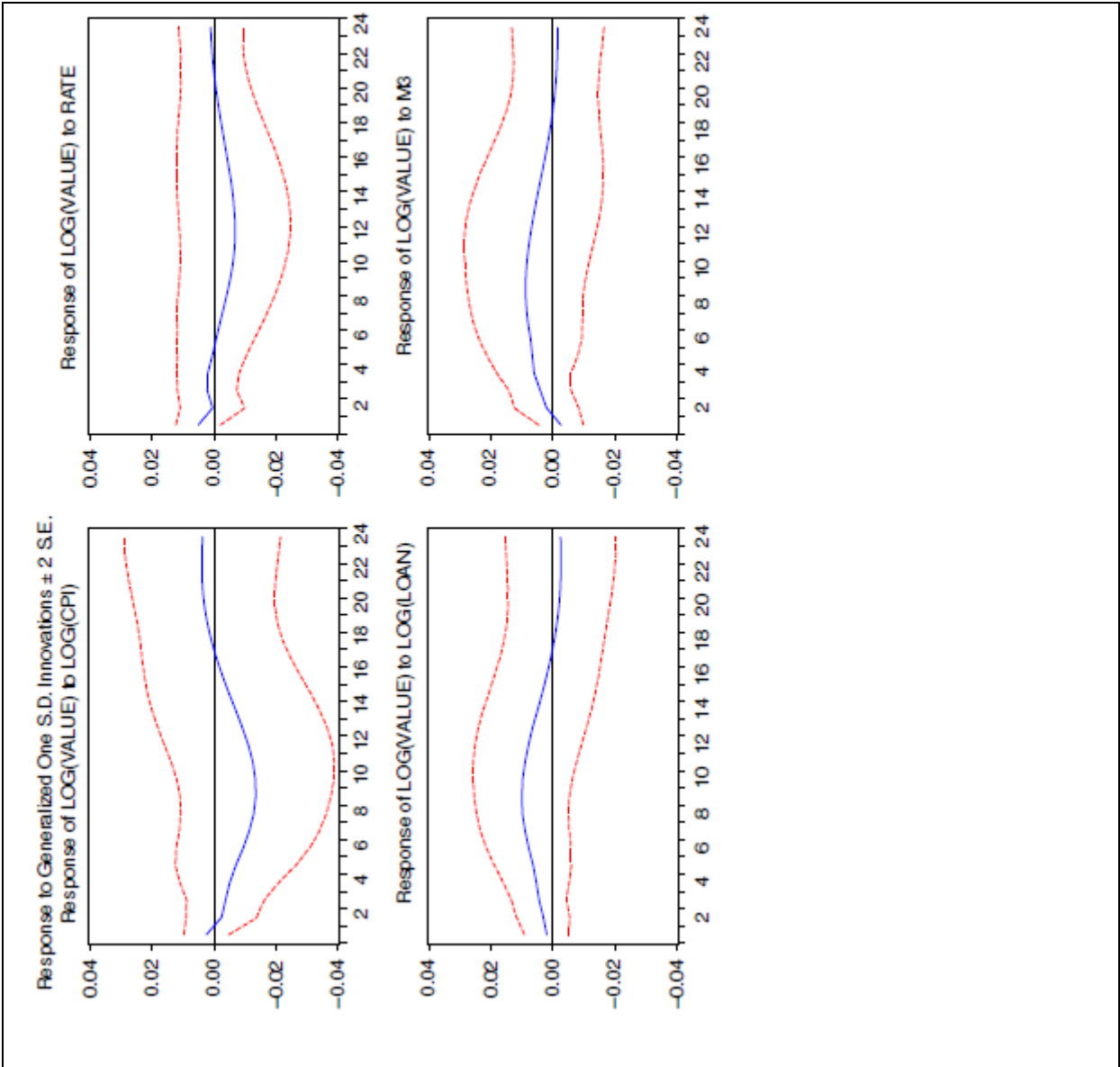
Figure 2.A1. Impulse-responses in the VAR rental price model

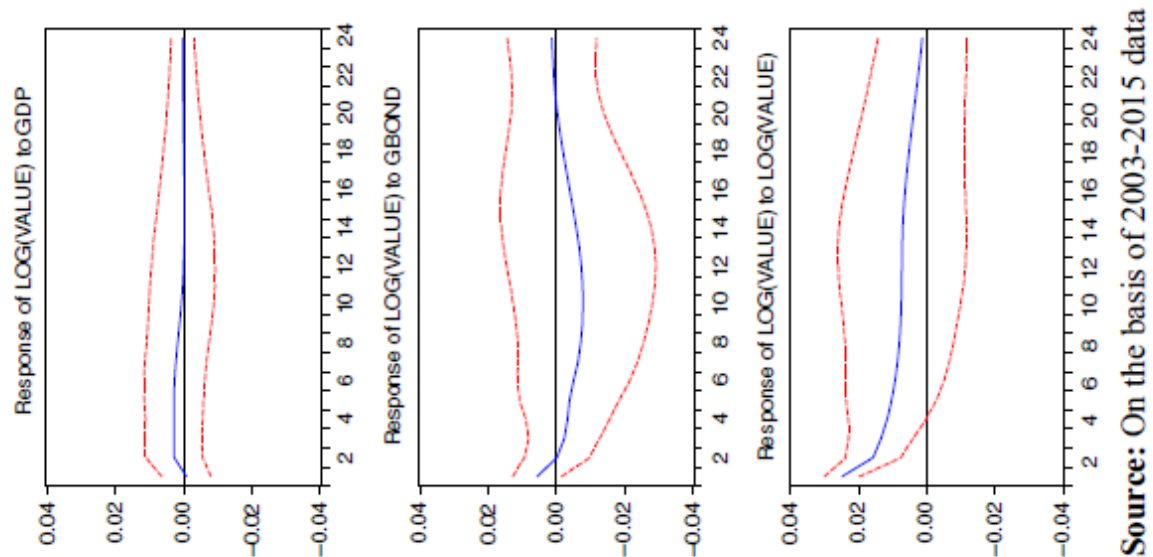




Appendix 3

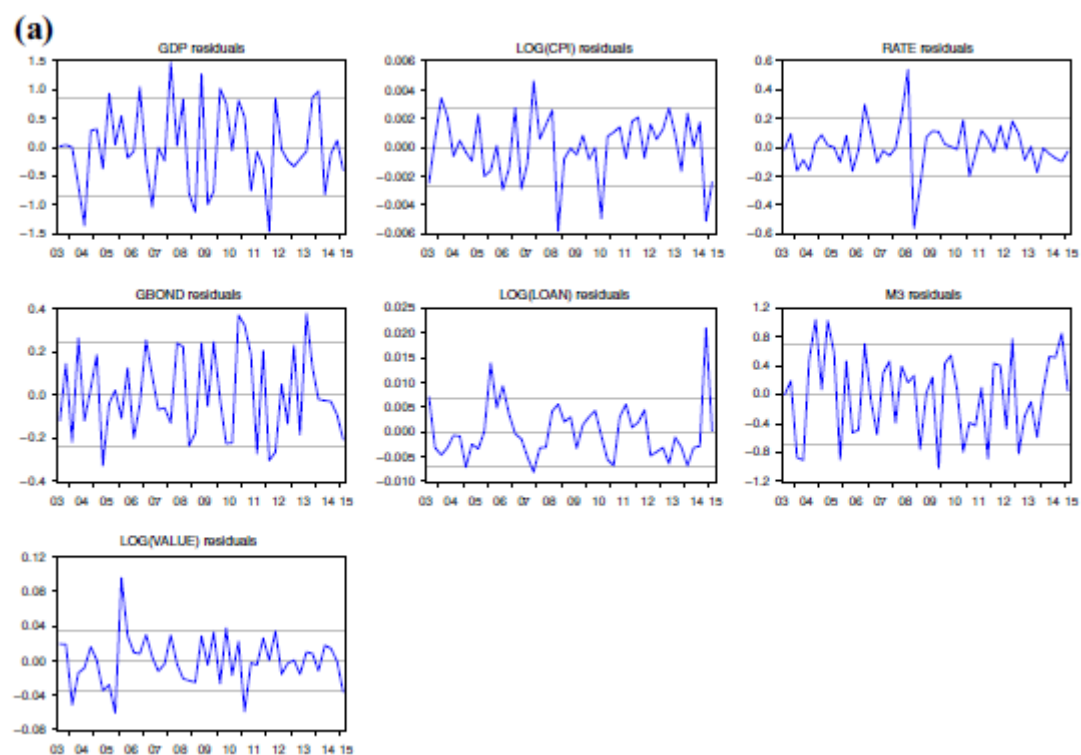
Figure 2.A2. Impulse-responses VAR capital value model



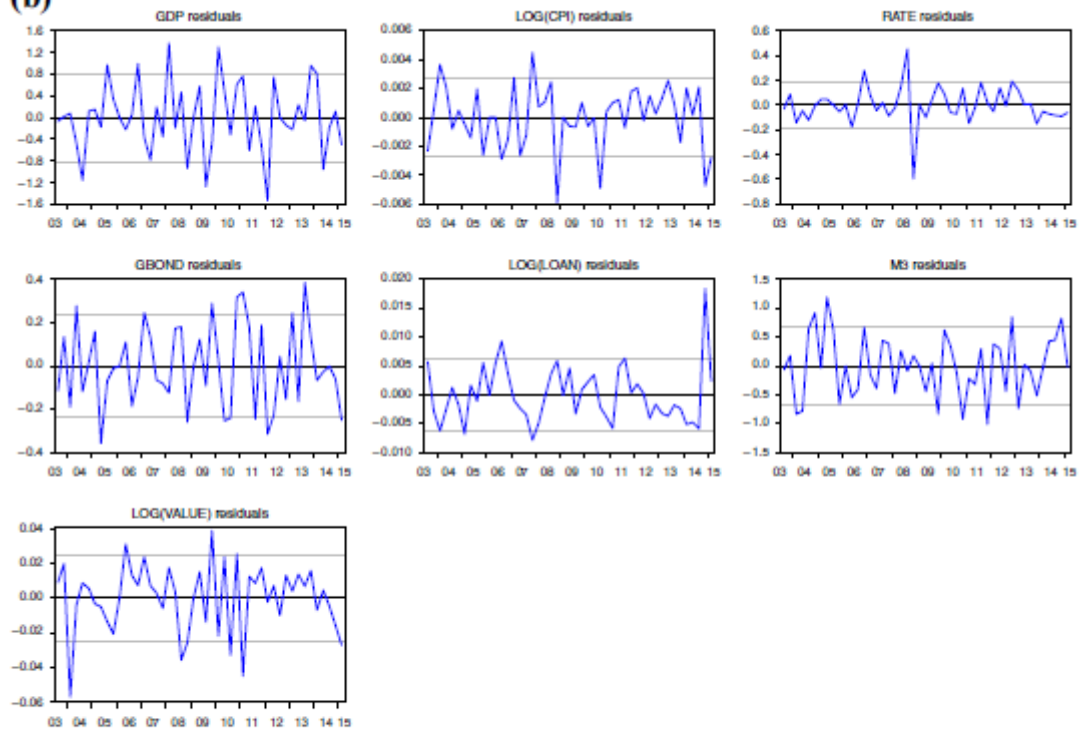


Appendix 4

Figure 2.A3. Residuals of the VAR capital value model



(b)



Notes: (a) Without distinct dummy variables for two market phases; (b) with distinct dummy variables for two market phases

3. How flood risk impacts residential rents and property prices – empirical analysis of a German property market

Purpose - This paper aims to quantify the impact of 100-year flood risk on both property rents and values in Germany, exemplified by the market of the historic city of Regensburg, and therefore supports investors in understanding market behavior patterns in both a rental and investment context.

Design/methodology/approach - We construct two Generalized Additive Models (GAMs) for rents and purchasing prices with spatial components and under inclusion of both typical property characteristics (as control variables) and a 100-year flood risk parameter in order to estimate its effect on the rents and property price structure. We apply the methodology to a 4-years data set of more than 16,500 observations.

Findings - The analysis shows that flood risk is a highly significant parameter when estimating both the rent as well as the sales price model. Also, we find that purchase prices for one square meter of living area are, on average, 299 EUR lower if the property is located in the flood risk zone. In addition, also rental markets come with a respective, but rather low, discount.

Practical implications - We provide transparency to investors in terms of the impact that a flood risk location has on property rents as well as purchasing prices. Our study supports investors by providing evidence on reaction patterns in German real estate markets and helps quantifying the financial impact that comes with flood risk in Germany.

Originality/value - This is the first study that aims to empirically test and to quantify the impact of flood risk on property rents and purchasing prices in Germany. Related research has been performed for the United States, Ireland and New Zealand and largely refers to event-driven work or rather conceptual in the context of property valuation.

3.1. Introduction

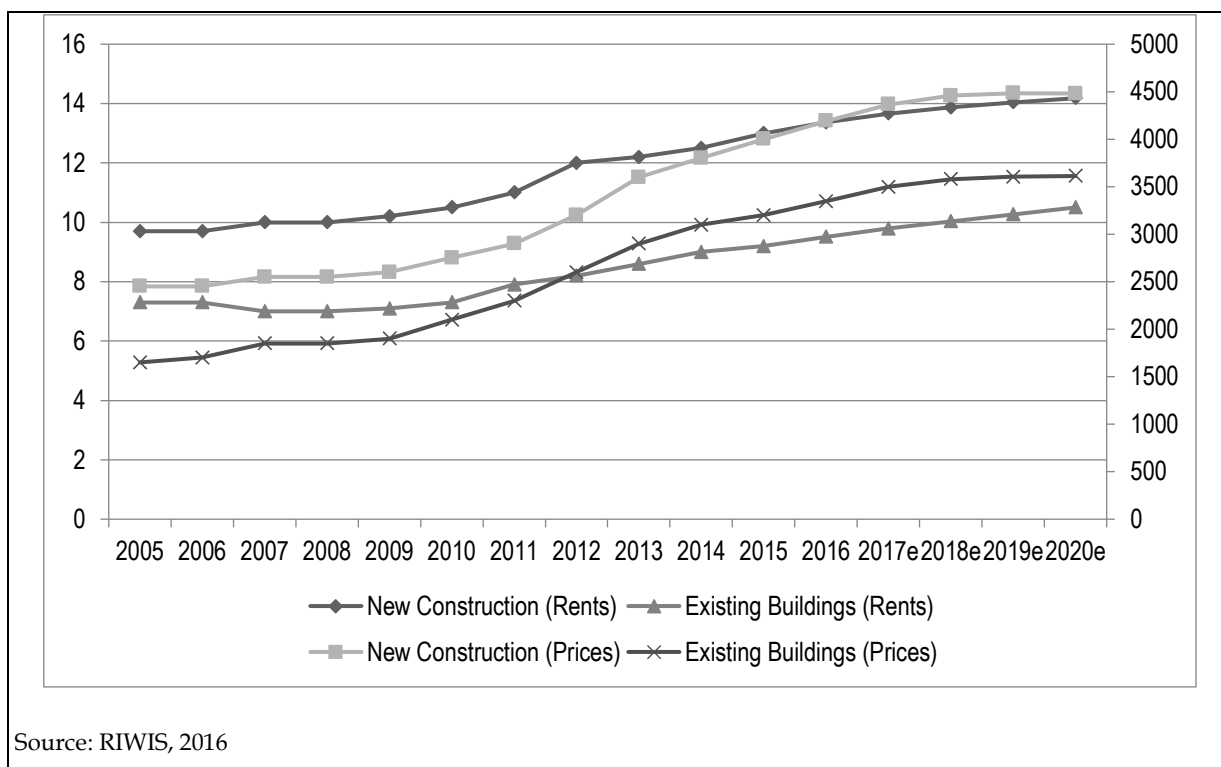
It was observed throughout the past decades that extreme weather events have increased significantly in terms of frequency, but also intensity (Stott, 2016). And indeed, flooding today depicts the second-most frequent cause for elementary damage in Germany (just after storms) with major implications for property owners or the insurance industry. It is expected that severe flood events will occur more frequently in the future and real estate depicts one major field of damage and therefore is connected to high economic vulnerability. That is why we intend to quantify the impact of flood risk on residential property markets in Germany.

When analyzing the impact of flooding on a property market, we advise to clearly define the regional scope upfront and to work on a local basis in accordance with Montz, 1992. We argue that this is due to three reasons: firstly, the property market is a regionalized system considering many local features such as the micro-supply and demand level. These factors are very heterogeneous throughout a country. And while it would be interesting to have a one-fits-all housing model for Germany, significant results should only be expected as soon as the regional influences can be fully reflected. Secondly, regional hydrologic situations are very different. For example, the difference in inundation depth between a one-in-50-years event and a one-in-100-years-event might be rather small in one city or rather big in another one. And thirdly, this leads to a specific local flooding adaption and protection situation, which is at this point not comparable or measurable in an econometric way, but subject to the local requirements, financial space and political design. Therefore, we perform our study covering the regional property market of Regensburg in the state of Bavaria in Southern Germany.

The historic old town of Regensburg is a UNESCO World Heritage site and well-known for its ancient Roman structures and medieval buildings and flair. Regensburg is a city of 150,000 inhabitants, located at the most northern point of the Danube River. In addition, two other rivers (the 'Naab' and the 'Regen') disembugue into the Danube in the city region. However, truly severe events have been rare lately and the floods of 1988, 2002 or 2013 had the dimension that is expected approximately every 20 years ('HQ20'). The town features a very vibrant property market: on the one hand side a university town, on the other hand side a mixture of local SMEs and international businesses increase the demand for housing in the city significantly, while vacant land has become a scarce resource. In the first half of 2016, a square meter of newly constructed condominium in the city center is traded at approximately 4,000 EUR (average), while monthly rents stay relatively moderate at 13 EUR per square meter in

new buildings. The following illustration gives further details on the recent price development.

Figure 3.1: The development of rents and condominium prices in Regensburg



Throughout the 80-or-so square kilometers of area, the city has developed several flooding adaption measures, in order to be prepared at least for a 25-year event ('HQ25'). While several of these have already been implemented throughout the eastern and northern part of the town, especially permanent measures for the city center as well as the western and high northern region are still subject to planning or construction.

The purpose of this paper is to combine the flood risk with the property markets and to analyze which relation exists between these factors. We therefore intend to investigate

1. Whether there is a significant relationship between the flood risk and the property rents and purchasing prices in the city of Regensburg, and
2. Which impact direction as well as impact strength this relationship features.

For this purpose, we construct two Generalized Additive Models (GAMs) for rents and purchasing prices with spatial components, where we include both typical property characteristics (as control variables) and a flood risk parameter in order to estimate its effect on the rents and property price structure. This is supported by panel data on purchase prices and rent information covering the years 2012 to 2015, including a total of 16,811 observations.

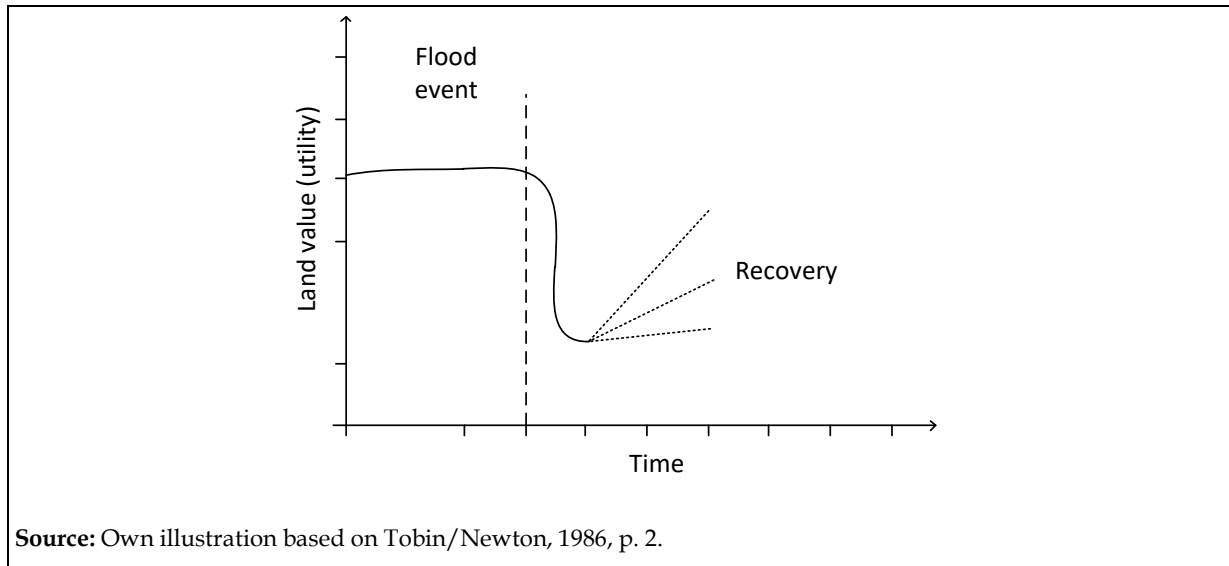
The rest of this paper is structured as follows: in the following chapter, we summarize and discuss fundamental and current literature and identify the research agenda on this field so far. In section 3, we perform the empirical analysis and explain the data, the methodology used as well as our results in greater detail, before we conclude this work in section 4.

3.2. Literature Review

There is no extensive (empirical) analysis of property prices in Germany in the context of existing flood risks. However, there is a range of international studies, primarily from anglophone regions that discuss the impact of flood risks on property markets. The data and literature available is in this context limited to individual regions, while the transferability of these insights is barely generalizable. In this section, underlying data challenges will be discussed and existing results of fundamental and specific nature will be summarized and put into context. In one of the most comprehensive studies of this field, Harrison, Smersh and Schwartz, 2001, have examined approximately 30,000 property transactions in Alachua County, Florida, between 1980 and 1997, and raised the question whether property values would develop differently if the respective properties were located in the risk zone of an extreme, 100-year flood event ('HQ100'). Indeed, the study confirmed a negative impact of flood risk on property values; however, the impact appears on average lower than the price of an adequate insurance. In another study, Tobin and Newton, 1986, investigate how the values of properties have reacted, which were actually affected by a flood event. While they also find a negative impact and this may apply to both flood events as well as the potential flood risk, the most interesting insight was that over the time span observed, a so-called 'bounce back' effect occurred amongst market participants over time. The 'bounce back' effect describes that prices recover after a certain time, having dropped suddenly after a flood event due to the damage and costs incurred; however, the market seems to forget about all these aspects over a certain time, and prices recover.

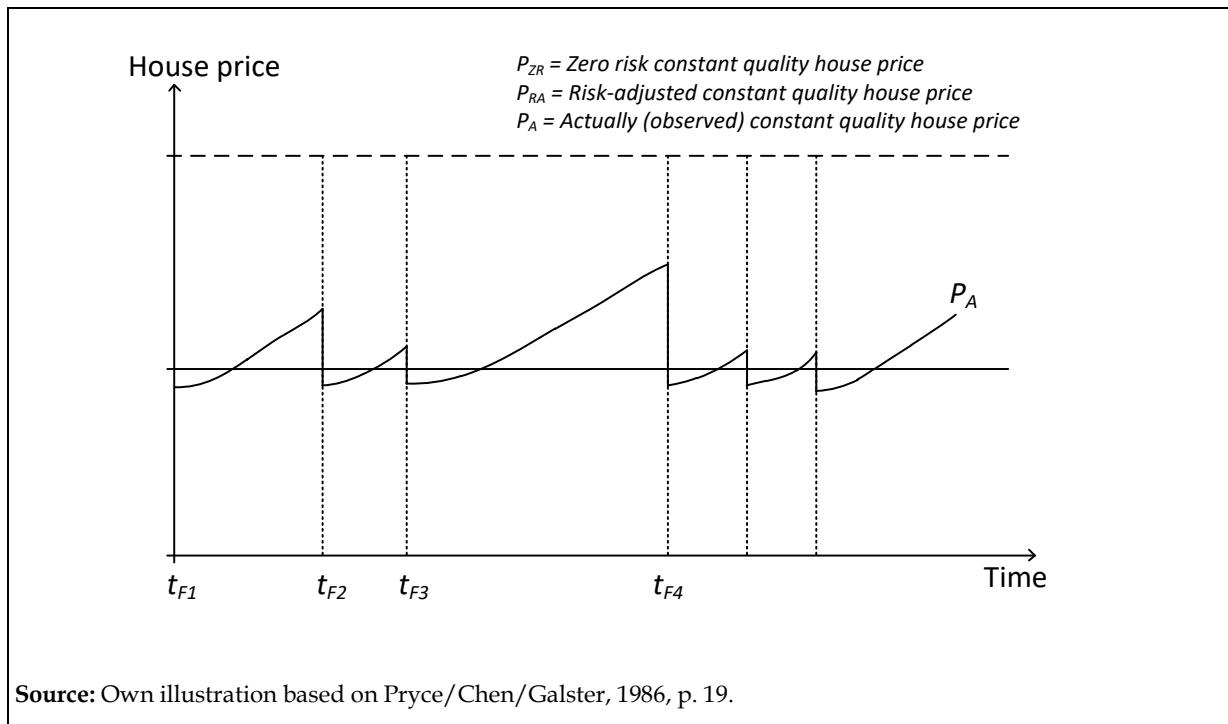
The fundamental idea is shown in the following illustration on the basis of land value considerations.

Figure 3.2: The ‘bounce back’ effect in property markets after flood events



According to their study, however, prices may not only recover over time, but at a certain point may even exceed the ex-ante value before the flood event happened. They explain this phenomenon by recovery work of the property, which may be combined with renovation or actual improvement of the building and its substance or quality (such as an energy-efficiency retrofit), which is performed within the frame of necessary recovery works. Although *Tobin and Newton, 1986*, have not used actual property price information, their theory is considered as ascertained today. Also, *Pryce, Chen and Galster, 2011*, have built on this idea and extended it in terms of recurring events, affecting the ‘bounce back’ effect with shorter periods between two events showing more moderate price drops than in longer periods. This observation is shown in the following illustration.

Figure 3.3: Multiple ‘bounce back’ effects over time



They argue that events from the nearer past are inherently over-weighted by the market in comparison to events from longer ago, even if those may have been more severe. They argue that risks are overestimated in the short term (market prices below the risk-adjusted constant quality house price, cf. fig. 4), while underestimated or even forgotten in the long term (above). This effect seems to exist even more, if external buyers enter the market and therefore information asymmetries are on hand. The authors conclude that external buyers do not seem to take the trouble of evaluating and pricing in past events.

Tobin and Montz, 1994, generalize a conceptual framework for the identification of the effect of flood risk on property values. Testing of the framework shows that the reaction to flood hazard and the related recovery period is driven by capital availability, future flood expectations and other property market characteristics.

Bin and Polasky, 2004, perform an event-driven study on the impact of Hurricane Floyd of September 1999 in Pitt County, North Carolina. Estimating from more than 8,000 single-family houses and price information from between 1992 and 2002, the authors show that a location within the flood-prone area significantly decreases the property value, and that this discount is significantly larger after Hurricane Floyd. The study also points out that the price discount

is larger than the capitalized flood insurance costs after Floyd, but was less than these costs before the event. This overall situation is also confirmed by *Speyrer and Ragas, 1991*, who investigated 2,000 residential properties in Greater New Orleans between 1971 and 1986 and found a negative impact of location in a flood-prone area on property values. The application of splines regression did improve the model quality and fit and also showed that a large portion of this value reduction happens due to increased insurance costs. Based on this specific data sample, the authors found that primarily unexpected flood events enforce the implicit pricing of the risk, while recurring events do not decrease property values any further.

In their analysis, *Bin et al., 2008*, incorporate the perspectives of both flood risk as well as water amenities in the specific context of a coastal region in North Carolina. The spatial-lag based study of 1,075 single-family residential homes finds that the 100-year flood prone area and the connected risk reduces property values by approximately 11 %, while the water amenities, measured as distance to the nearest beach, would generally come with a \$854 increase in average property value per 10-yard distance. *Bin et al.* also suggest approaches for approximating water amenities such as an extraordinary view in the analysis. *Daniel, Florax and Rietveld, 2009*, perform a meta-analysis of several US studies on implicit pricing of flood risk and conclude that a 0.01 increase in probability of flood risk in a year comes with a difference in transaction price of minus 0.6 %. Also, an actual flood event is observed to change ex-post prices, however to a rather marginal extent. Also, the study finds a biasing influence of amenity effects and risk exposure in locations close to water.

In one of the rare studies on outside the US, *Montz, 1992* investigates three local regions in New Zealand on flooding and its impact on residential values. Although the study finds different reaction patterns amongst these communities, a generally common negative effect is confirmed. Also, differences in flooded and non-flooded submarkets decrease over time, so that the flood hazard does not depict a long-term value determinant.

Chen, Pryce and Mackay, 2011, have postulated four criteria, where research has drawn wrong conclusions on the impact of flooding or flood risk on property markets so far. These comprise

1. The assumed permanence of property market structures (first-time vs. regular flooding) and the properties included (why was the particular property sold after the event?). Also, they advise to consider the fact that prices may be higher in flood-prone areas if these areas show higher demand patterns for other reasons.

2. The generalization of one-time actions (will insurance money always be available to compensate?). Not only in the state of Bavaria, insurance companies started becoming more restrained in terms of new policies for properties in high-risk areas.
3. The non-linearity of flood severity and magnitude of damage. Magnitude includes indirect factors such as social effects or the need for changes in residence after very severe floodings.
4. The *ceteris paribus* assumption. Neighborhood interaction effects are underestimated, even if two properties in one neighborhood show different flood risk exposure.

Unfortunately, no solutions or workaround pathways were indicated by these authors.

Bienert, 2014, has discussed the rising threat of extreme weather events for real estate markets and outlined comprehensive theoretical information on their monetary effect in terms of property values. In addition, aspects of cross-national importance including settlement strategies, measures for reducing risk exposure, as well as research output on different economic sectors (including agriculture, forestry and real estate) were collected and contrasted.

And ultimately, in addition to the international research conducted, *Hirsch, Braun and Bienert, 2015*, have focused on Germany and developed a methodology for estimating the damage rate and related annual expected losses in property value from diverse types of extreme weather events, including floods; this methodology was practically applied for several German housing markets. By incorporating risk and hazard data on climatic events, regional vulnerability in Germany as well as appraised property values, their concept delivered theoretical appraisals and therefore provided groundwork for the present empirical study.

In the following section, we will perform the empirical analysis of this paper in the light and under consideration of the former research findings as outlined in this review of literature.

3.3. Empirical Analysis

Data

This analysis is based on a private dataset of 16,811 observations, thereof 7,777 on properties for sale and 9,034 on properties for rent. The data panel contains real estate price information (purchasing prices or rents, as offered on Germany's largest and market-leading property portal) from the years 2012, 2013, 2014 and 2015. The price information reflects asking prices

and is connected to property characteristics as complemented by the seller, owner or agent who is responsible for the offering. These characteristics comprise, for instance:

- The building year
- The property's living area
- The storey within the property
- The type of building, and so forth

However, most of these characteristics are not mandatory input parameters on the portal and may therefore be unavailable for a certain property, but the analysis will only consider complete entries. An information, which is available for each and every property offered, is the geographic location, not necessarily as a street address, but (more effectively so) as x and y coordinates. If the coordinates were not available but the street address, we geocoded the properties in order to obtain missing coordinates. This makes it possible for us to source and add information on the micro-location's specific flood risk. In that procedure, we enrich the property characteristics and information by connecting it to flood-prone areas, as provided by the Bavarian Office for the Environment ('Bayerisches Landesamt für Umwelt', LfU). Specifically, we source information on 'HQ100', the area to be expected as flooded in case of a rather extreme 100-year event and, in a further model, the respective inundation depths for this event, as well as the 'distance-to-river' control variable.

Expectations

Derived from own perception as well as the fundamental assumption of rational market participants, we postulate the following expectations to be tested in this work:

E1: Purchase prices are lower with flood risk, as a functioning market incorporates the possible costs for re-building

E2: Rents are constant as tenants do not carry major financial property risk in the case of events or marginally reduced as landlords pass along the lower purchasing prices

Methodology

In this empirical analysis, we construct two Generalized Additive Models (GAMs) for selling prices and rents incorporating property characteristics, geographic information as a spatial component as well as connected flood risk and property values or rent information. GAMs have the advantage that they are not based on the general assumption of a linear effect of the variables on prices, but rather allow for smooth functions describing the relations. Our GAMs follow the fundamental form, as shown below:

$$Y = f_0 + \sum_{j=1}^p f_j(X_j) + \varepsilon$$

where errors ε are independent of X_j , $E(\varepsilon) = 0$ and $\text{Var}(\varepsilon) = \sigma^2$ and f_j describes univariate smooth functions, one for each variable included, in order to account for possible non-linearity.

We incorporate property rent or property value as Y and the flood risk as one explaining variable. Furthermore, we incorporate several property characteristics as well as geographic information as control variables. Consequently, we estimate:

$$\log(\text{RentPerSQM}) = f_0 + f_1 \text{FloodRisk}_{location} + \sum_{j=2}^p f_j(X_j) + \varepsilon$$

where p is the number of control variables. Simultaneously, we estimate the purchasing price GAM as follows:

$$\text{PricePerSQM} = f_0 + f_1 \text{FloodRisk}_{location} + \sum_{j=2}^p f_j(X_j) + \varepsilon$$

where p is the number of control variables. The control variables applied are the coordinates of the respective property as a location parameter, the year of the price information (in order to control for market movements and the impact of timing in market transactions), the total number of rooms, the size of the property in square meters as well as the building year (in order to control for age) and the distance to the next river. Both the flood risk variables as well as the distance to a river variable are derived by means of Geographic Information Systems (GIS).

As a cross-check for the results of this analysis, we perform an additional analysis, where we specify the flood risk variable and expand it to an indicator on expected water depth in the case of 100-years event. This variable is included as a factor in order to derive more specific

information on groups of affected properties and for plausibility checking of our original results.

Results

Table 3.1: Output of results regarding flood risk

	Rental Model	Sales Model
Location within flood prone area	-1.806 % *	-299.34 EUR ***
Standard Deviation	+/- 0.8174 %	+/- 30.71 EUR

Significance Information: 0 '****' 0.001 '***' 0.01 '**' 0.05 '.' 0.1 ' ' 1

Table 3.2: Output of results regarding specific water depths (standard deviation in brackets)

Location Specific Flood Depth in 100-year event	Rental Model	Sales Model
Flood Water Level 1 (low)	-1.8779 % . (+/- 1.1013 %)	-220.03 EUR *** (+/- 33.92 EUR)
Flood Water Level 2	-2.9265 % * (+/- 1.3795 %)	-526.37 EUR *** (+/- 49.32 EUR)
Flood Water Level 3	-0.9304 % (+/- 1.2844 %)	-350.50 EUR *** (+/- 76.61 EUR)
Flood Water Level 4 (high)	+2.0780 % (+/- 5.0639 %)	-303.31 EUR (+/- 433.674 EUR)

Significance Information: 0 '****' 0.001 '***' 0.01 '**' 0.05 '.' 0.1 ' ' 1

Our analysis shows that the flood risk is a highly significant parameter when estimating both the rent as well as the sales price model. The result for the rental market is significant at 5 % level (*), for purchases even at 0.1 % level (***). We find out that purchase prices for one square meter of living area are, on average, 299 EUR lower if the property is located in the HQ100 flood risk zone (standard deviation: 30.71 EUR). This discount can, indeed, be assigned to the flood risk, as location differences within the city itself were controlled for separately. This confirms our hypothesis H1 that in a functioning market, possible costs for recovery after

damage are priced into the sales price. In this case, this discount in pricing is actually performed already by the seller who is aware of the higher risk of the location.

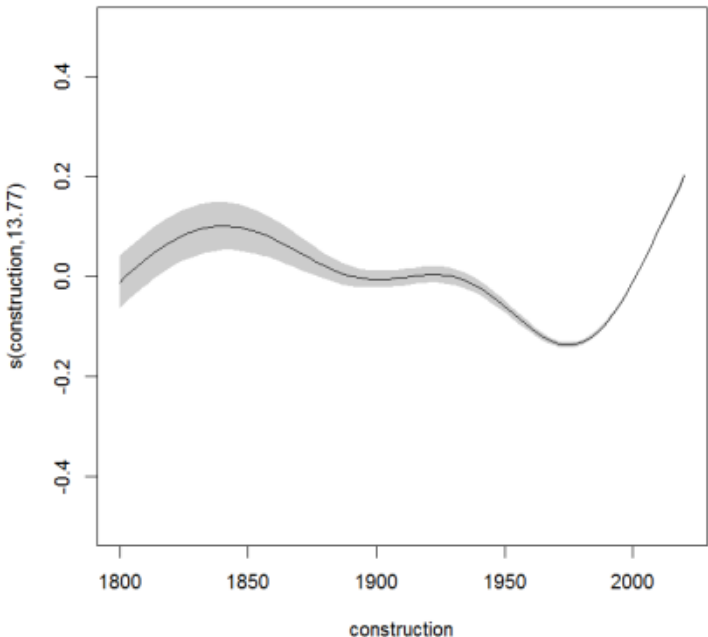
As illustrated earlier in this work, Regensburg properties are currently traded at around 4,000 EUR per square meter for new constructions or little more than 3,000 EUR per square meter for existing buildings, on average. In this context, 299 EUR in property value per square meter are a relatively significant impact that is clearly relevant for market actors and decision making or investment. However, the value cannot systematically be transferred to other local markets in Germany due to their individual pricing structures (cf. Introduction for further discussion on this).

Regarding the rental market, we make a rather surprising observation: ex-ante, we expected rents to be constant and to neglect the effect of flooding, as tenants do not carry major financial property risk in the case of flood events. However, the analysis shows that the flood risk seems to have a negative impact direction at a very high significance level. The location within the flood risk area, under controlling for the location itself, seems to lead to lower rents in the range of -1.88 % (+/- 1.10 %). We understand this price discount to arise from residual costs that the tenant has to cover – although not responsible for covering property damage costs – for potential additional expenses (e.g. uninsured household goods) or inconvenience (e.g. in the case of a flood event in the particular area). Another possible explanation is that landlords are passing along the lower purchasing price of the property to the tenant.

The following results have been gathered on the control variables of the model: an additional room is observed with a rather moderate c.p. increase of square meter rents of 2.66 % (**), in purchasing prices even a moderate discount of 8.36 EUR per square meter for an additional room is observed (only significant at 10 % level, whatsoever). The spline graphs of the construction year show characteristic patterns such as the post-war indentation, typically explained together with the low-quality construction of that time. For Regensburg in particular, it seems to be true that old property is not necessarily rented or sold at a discount, but actually rented or sold with premia. The general market development of the city has shown a de-coupling of rental and purchasing prices. While the general rent development observed between 2012 and 2015 shows rather stable prices with an increase of 5 % in that time frame, purchasing prices have – on average – achieved an increase of approximately 500 Euros per square meter. The distance to the next river shows basically no impact on rent prices within a

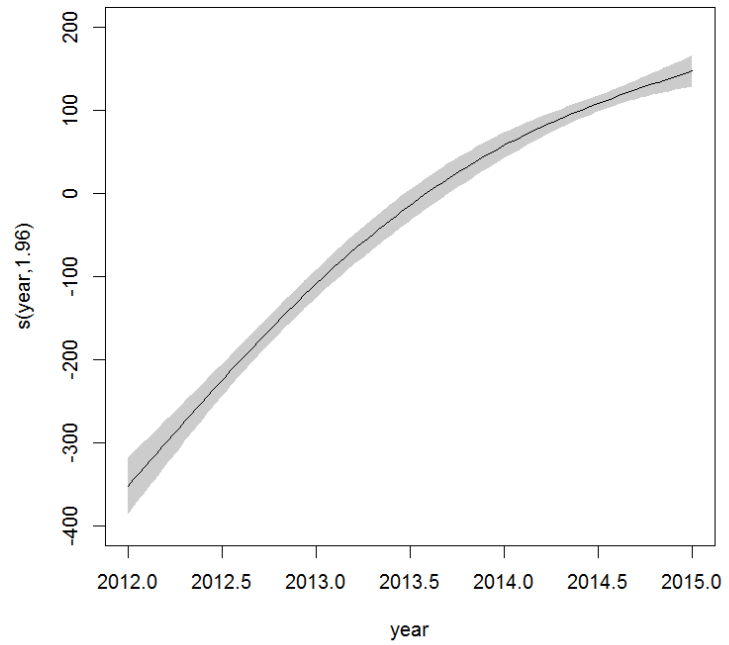
1 kilometer radius, and a decrease of up to 10 % within the next 500 meters. On the purchasing market, however, a rather constant decrease of the impact can be observed. And ultimately, the area of the property shows a classical pattern of small-area, but relatively more expensive (student) housing and a rather high consistency between 50 and 150 square meters. On the purchasing market, the segmentation of the market can be clearly derived with an initial price drop from expensive student and single apartments (up to 40 square meters), through single-family housing around 100 to 170 square meters (with a price peak at around 150), a further drop down to the size of 250 square meters, and eventually an additional increase in the segment of multifamily housing going further. The output and spline patterns of these variables are outlined in the table below.

Table 3.3: Output of the control variables in the Rental and Sales Model

<i>All effects c.p.</i>	Effect of (Additional) Rooms
Rental Model	+ 2.6579 % (+/- 0.2673 %) ***
Sales Model	-8.36 EUR (+/- 4.293 EUR) .
	Significance Information: 0 '****' 0.001 '***' 0.01 '**' 0.05 '.' 0.1 ' ' 1
	Effect of the Construction Year
Rental Model	

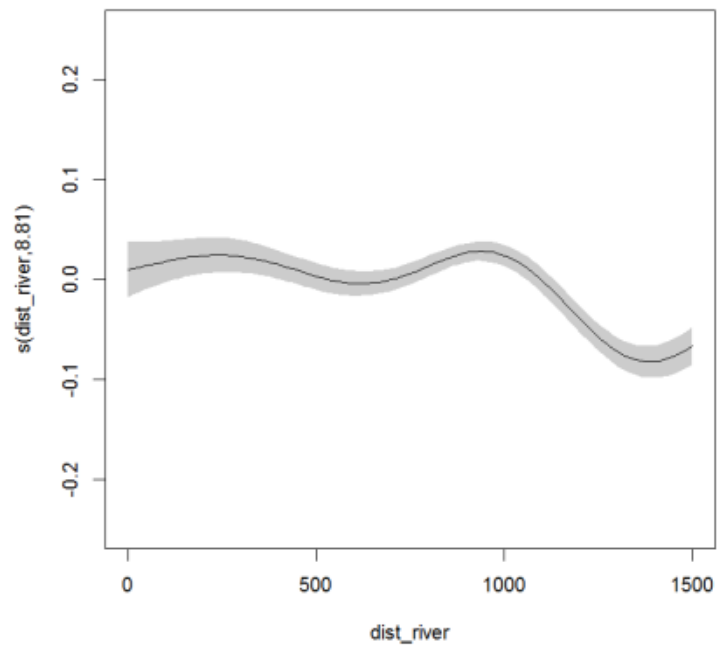
<p>Sales Model</p>	
<p>Effect of the Price Information Year (Market/Timing)</p>	
<p>Rental Model</p>	

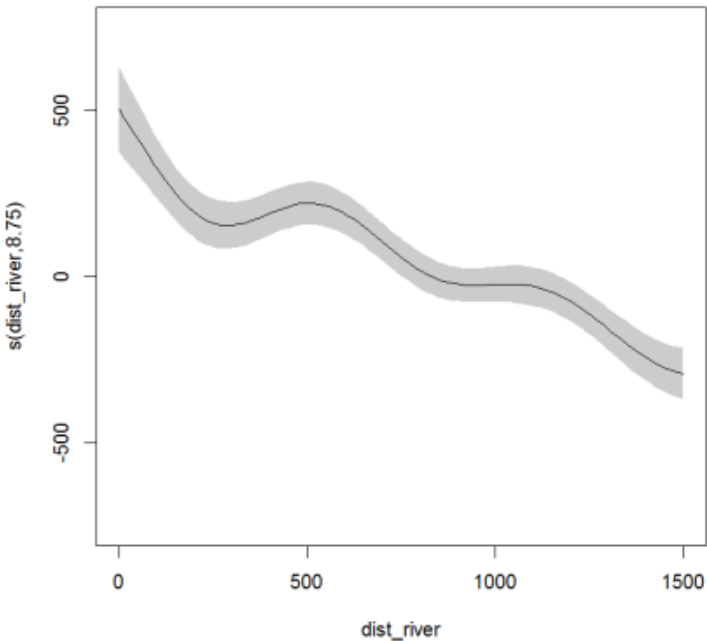
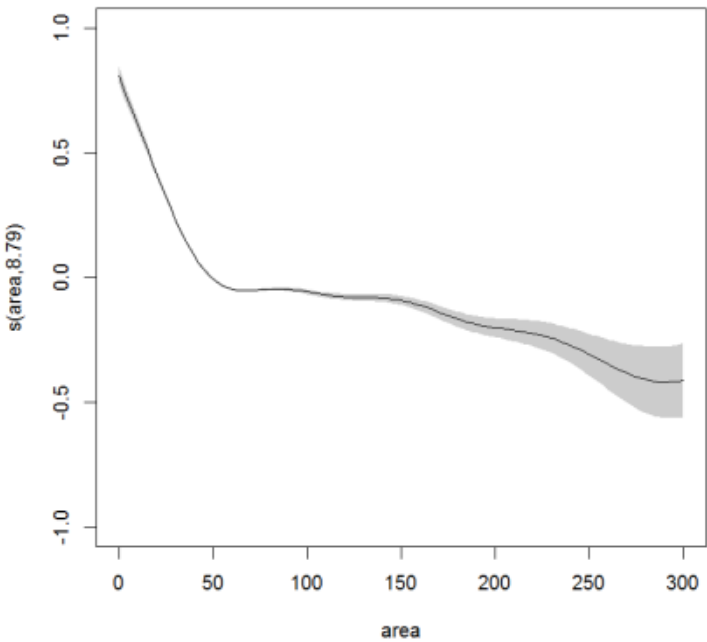
Sales Model

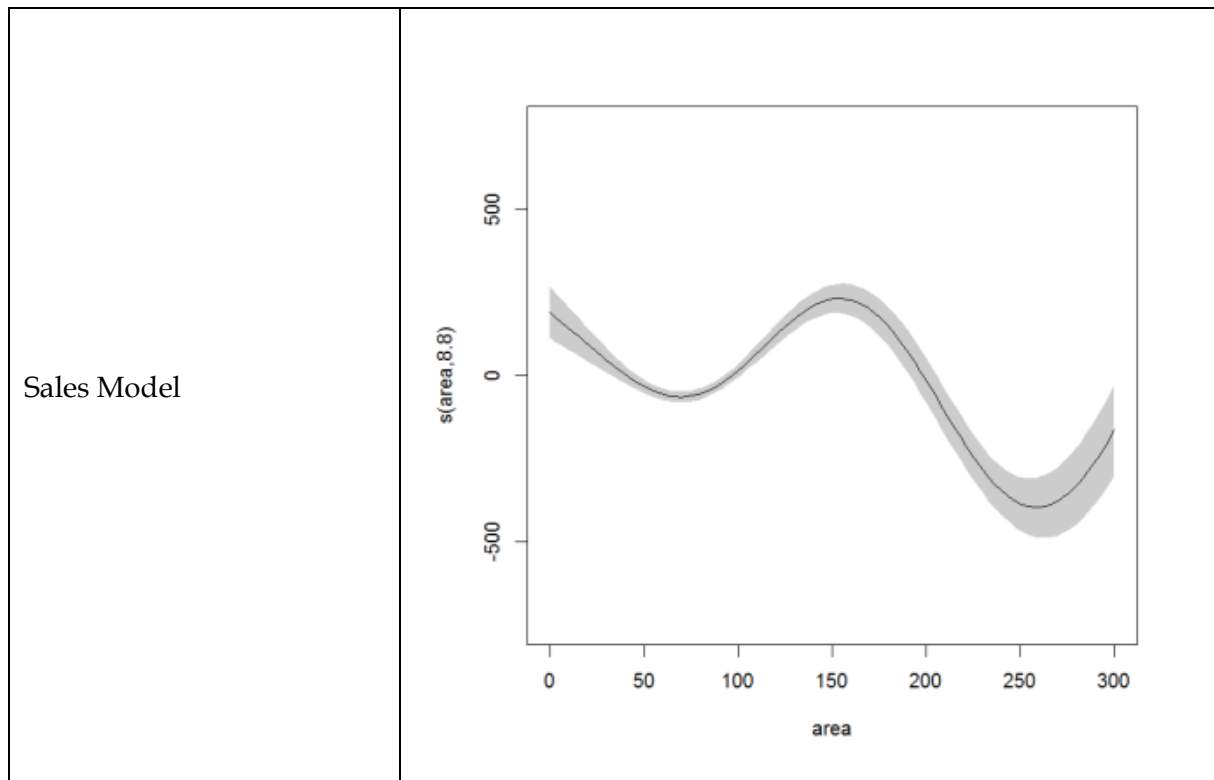


Effect of the Distance to the next River

Rental Model



Sales Model	
Effect of the Living Area	
Rental Model	



The full outputs as well as the splines for the building year variable, as well as a map showing the differences in the rent levels throughout the city on the basis of x and y coordinates are shown in the Annex.

3.4. Conclusion

This study reveals the empirical impact of flood risk on residential rents as well as purchasing prices in the case of Regensburg, Germany. The analysis has delivered that, while the sales market seems to work very rationally and prices in the potential costs of flooding damages to upcoming owners by a discount of, on average, 299 Euros per square meter, in the time period of 2012 to 2015, the rental market shows unexpected patterns. We expected tenants and rent prices to be indifferent toward flood risks, as they do not carry financial risk for damages of the property. However, the actual patterns seem to incorporate non-physical downsides to tenants, who on the one hand side do not carry any financial risk for the property in the case of a flood event, but even seem to appreciate the flooding exposure in the sense of a significant (*), but marginal rental discount. As we have controlled for rental differences due to the micro-location separately, we expect this to arise from negative factors that tenants have to face in the case of a flood event, although they are not financially disadvantaged by the property damage costs. However, landlords seem to accept the fact that nevertheless, inconveniences

from e.g. cleaning work as well as potential other expenses (e.g. uninsured household goods) may put a burden on the tenant. However, the rent price discount quotes rather marginal at, on average, 1.8 %.

The empirical insights delivered by this work confirm previous analysis and theoretical considerations. Specifically, this study confirms the existence of market pricing mechanisms, which include annual expected losses due to the financial risk from extreme weather events that were previously postulated through theoretical groundwork. And as the whole complex of extreme weather events and real estate impact is gaining significant importance (especially in times of climate change), this price determinant should receive more elaborate consideration in property valuation and transaction pricing in the future.

In addition to the comprehensive insights into a local German real estate market, this study also proved the role of water to be two-fold. On the one hand-side, we did clearly measure an impact of water as an amenity due to the recreational power of water in an urban location and environment. It turns out to become a market determinant in the sense that a higher distance to this natural recreation facility leads to clear price discounts and in sales markets, distinct price premiums are estimated for properties with close distance.

On the other hand, the amenity of water location comes with an undisputable natural risk, which is indeed also priced in by market actors. Based on the insights from this study, investors may now better understand the respective market reaction patterns and can base their calculations on pricing and profitability as well as their climate change or insurance strategy on further empirical evidence.

Limitations of the study

The present study comes with a couple of limitations that should be considered when drawing conclusions on the basis of this work. Firstly, we have not considered the differences of building equipment, quality or property types within the residential segment. These may be an additional explaining factor in terms of differences in rent or purchasing prices and therefore suitable control variables. Secondly, the private data set analyzed consists of asking prices and while Regensburg shows a high excess in demand and therefore depicts a supplier market, these prices may differ from the final contract price (especially in purchasing transactions). As such, the prices rather reflect the “willingness to demand” than a “willingness to pay”. And ultimately, the data set covers only retrospective information with

a selected time span of four years and although it contains 2013, a year that experienced a 20-year flood event, it is not possible to derive information on long-term effects or clear ‘bounce back’ recovery patterns on that basis.

Further research

We suggest expanding related research on other regions and cities in Germany to close the gap of empirical evidence on market behavior and reaction patterns in the case of flood risk or events. Furthermore the analyzed time span could be extended, especially in order to incorporate the effect of actual flood events. In addition, the data set may be combined with additional natural hazards, such as landslides or avalanches (where relevant), or systematically contrasted to actual flood insurance prices in order to identify gaps or overpricing in regional insurance premiums and to isolate properties with insurance protection to those without.

3.5. References

- Bavarian Office for the Environment, 2016: [Information Service – Flood Risk Areas]. http://geoportal.bayern.de/bayernatlas/iug/?theme=wasser_hochwassergefahren_flaechen, available in German, accessed October 13, 2016.
- Bienert, S., 2014: Extreme weather events and property values - Assessing new investment frameworks for the decades ahead. ULI Europe Policy & Practice Committee Report.
- Bin, O., T. Crawford, J. Kruse, and C. Landry, 2008: Viewscapes and Flood Hazard: Coastal Housing Market Response to Amenities and Risk. *Land Economics*, 84(3), pp. 434-448.
- Bin, O. and S. Polasky, 2004: Effects of Flood Hazards on Property Values: Evidence Before and After Hurricane Floyd. *Land Economics*, 80(4), pp. 490-500.
- Chen, Y., G. Pryce, and D. Mackay, 2011: Flood Risk, Climate Change and Housing Economics – The Four Fallacies of Extrapolation. Adam Smith Research Foundation Working Papers 2011:02, pp. 2-13.
- City of Regensburg, 2016: [Flood Protection Overview]. <http://www.hochwasserschutz-regensburg.de/startseite.html>, available in German, accessed October 13, 2016.
- Daniel, V., R. Florax, and P. Rietveld, 2009: Flooding risk and housing values: An economic assessment of environmental hazard. *Ecological Economics*, 69(2), pp. 355-365.

- Harrison, D., G. Smersh, and A. Schwartz, 2001: Environmental determinants of housing prices: the impact of flood zone status. *Journal of Real Estate Research*, 21(1/2), pp. 3-20.
- Hirsch, J., T. Braun, and S. Bienert, 2015: Assessment of climatic risks for real estate. *Property Management*, 33(5), pp. 494-518.
- Montz, B., 1992: The Effects of Flooding on Residential Property Values in Three New Zealand Communities. *Disasters*, 16(4), pp. 283-298.
- Pryce, G., Y. Chen, and G. Galster, 2011: The Impact of Floods on House Prices: An Imperfect Information Approach with Myopia and Amnesia. *Housing Studies*, 26(2), pp. 259-279.
- RIWIS, 2016: Data Excerpt from Regional Real Estate Information System, bulwiengesa Berlin/Munich.
- Speyrer, J. and W. Ragas, 1991: Housing Prices and Flood Risk: An Examination Using Spline Regression, *The Journal of Real Estate Finance and Economics*, 4(4), pp. 395-407.
- Stott, P., 2016: How climate change affects extreme weather events. *Science*, 352(6293), pp. 1517-1518.
- Tobin, M. and B. Montz, 1994: The Flood Hazard and Dynamics of the Urban Residential Land Market. *Journal of the American Water Resources Association*, 30(4), pp. 673-685.
- Tobin, M. and T. Newton, 1986: A theoretical framework of flood induced changes in urban land values. *Journal of the American Water Resources Association*, 22(1), pp. 67-71.

3.6. Annex

Table 3.A1: Output Rental Model

Flood Prone Approach

Formula:

```
logrentsqm ~ +s(construction, k = 15) + s(area) + s(year, k = 3) +
  rooms + s(dist_river) + flood100yr + s(geox, geoy, k = 20)
```

Parametric coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.161849	0.007270	297.350	<2e-16 ***
rooms	0.026579	0.002673	9.942	<2e-16 ***
flood100yr	-0.018060	0.008174	-2.210	0.0272 *

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(construction)	13.768	13.986	209.05	<2e-16 ***
s(area)	8.790	8.978	355.67	<2e-16 ***
s(year)	1.966	1.999	61.96	<2e-16 ***
s(dist_river)	8.808	8.989	28.94	<2e-16 ***
s(geox,geoy)	18.459	18.959	39.49	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.483 Deviance explained = 48.6%

GCV = 0.024734 Scale est. = 0.024584 n = 9034

Flood Depths Approach

Formula:

```
logrentsqm ~ +s(construction, k = 15) + s(area) + s(year, k = 3) +
  rooms + s(dist_river) + factor(flood100depth) + s(geox, geoy,
  k = 20)
```

Parametric coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.161700	0.007273	297.209	<2e-16 ***
rooms	0.026623	0.002674	9.955	<2e-16 ***
factor(flood100depth)1	-0.018779	0.011013	-1.705	0.0882 .
factor(flood100depth)2	-0.029265	0.013795	-2.121	0.0339 *
factor(flood100depth)3	-0.009304	0.012844	-0.724	0.4688
factor(flood100depth)4	0.020780	0.050639	0.410	0.6816

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(construction)	13.768	13.986	208.39	<2e-16 ***
s(area)	8.790	8.978	355.81	<2e-16 ***
s(year)	1.966	1.999	61.85	<2e-16 ***
s(dist_river)	8.804	8.988	29.05	<2e-16 ***
s(geox,geoy)	18.456	18.959	39.31	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.483 Deviance explained = 48.6%

GCV = 0.024746 Scale est. = 0.024587 n = 9034

Table 3.A2: Output Sales Price Model**Flood Prone Approach**

Formula:

```
salespricesqm ~ +s(construction, k = 15) + s(area) + s(year,
  k = 3) + rooms + s(dist_river) + flood100yr + s(geox, geoy,
  k = 20)
```

Parametric coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	3263.313	17.421	187.322	<2e-16 ***
rooms	-8.364	4.293	-1.948	0.0514 .
flood100yr	-299.336	30.714	-9.746	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(construction)	13.639	13.964	249.726	< 2e-16 ***
s(area)	8.797	8.985	34.432	< 2e-16 ***
s(year)	1.956	1.998	261.502	< 2e-16 ***
s(dist_river)	8.747	8.980	9.206	4.61e-14 ***
s(geox,geoy)	18.599	18.976	91.471	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.506 Deviance explained = 50.9%

GCV = 3.7274e+05 Scale est. = 3.7012e+05 n = 7777

Flood Depths Approach

Formula:

```
salespricesqm ~ +s(construction, k = 15) + s(area) + s(year,
  k = 3) + rooms + s(dist_river) + factor(flood100depth) +
  s(geox, geoy, k = 20)
```

Parametric coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	3261.619	17.393	187.530	< 2e-16 ***
rooms	-7.472	4.289	-1.742	0.0815 .
factor(flood100depth)1	-220.025	33.917	-6.487	9.28e-11 ***
factor(flood100depth)2	-526.373	49.322	-10.672	< 2e-16 ***
factor(flood100depth)3	-350.501	76.612	-4.575	4.84e-06 ***
factor(flood100depth)4	-303.311	433.674	-0.699	0.4843

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(construction)	13.587	13.953	236.16	<2e-16 ***
s(area)	8.814	8.987	35.28	<2e-16 ***
s(year)	1.951	1.998	263.68	<2e-16 ***
s(dist_river)	8.787	8.985	10.54	<2e-16 ***
s(geox,geoy)	18.608	18.977	91.24	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.508 Deviance explained = 51.2%

GCV = 3.7129e+05 Scale est. = 3.6853e+05 n = 7777

Figure 3.A1: Isolated Effect of Location on Rents

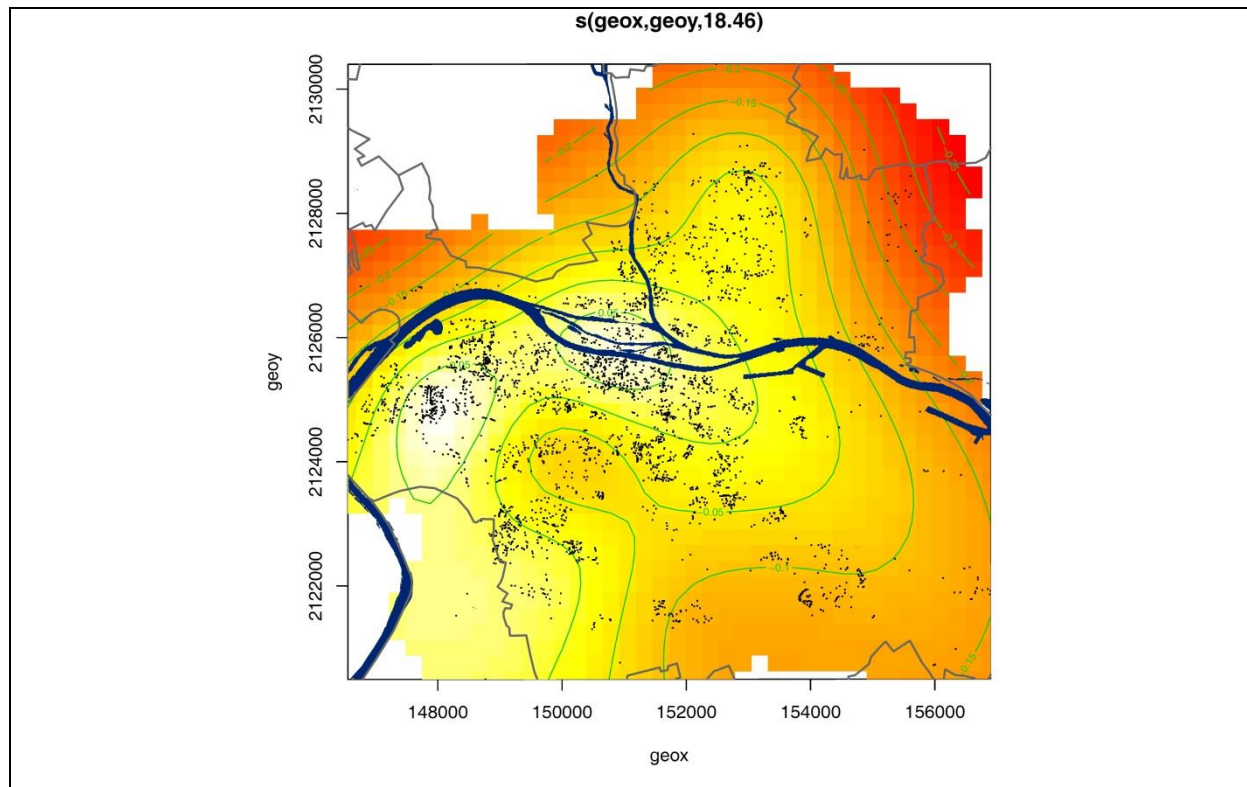


Figure 3.A2: Isolated Effect of Location on Sales Prices

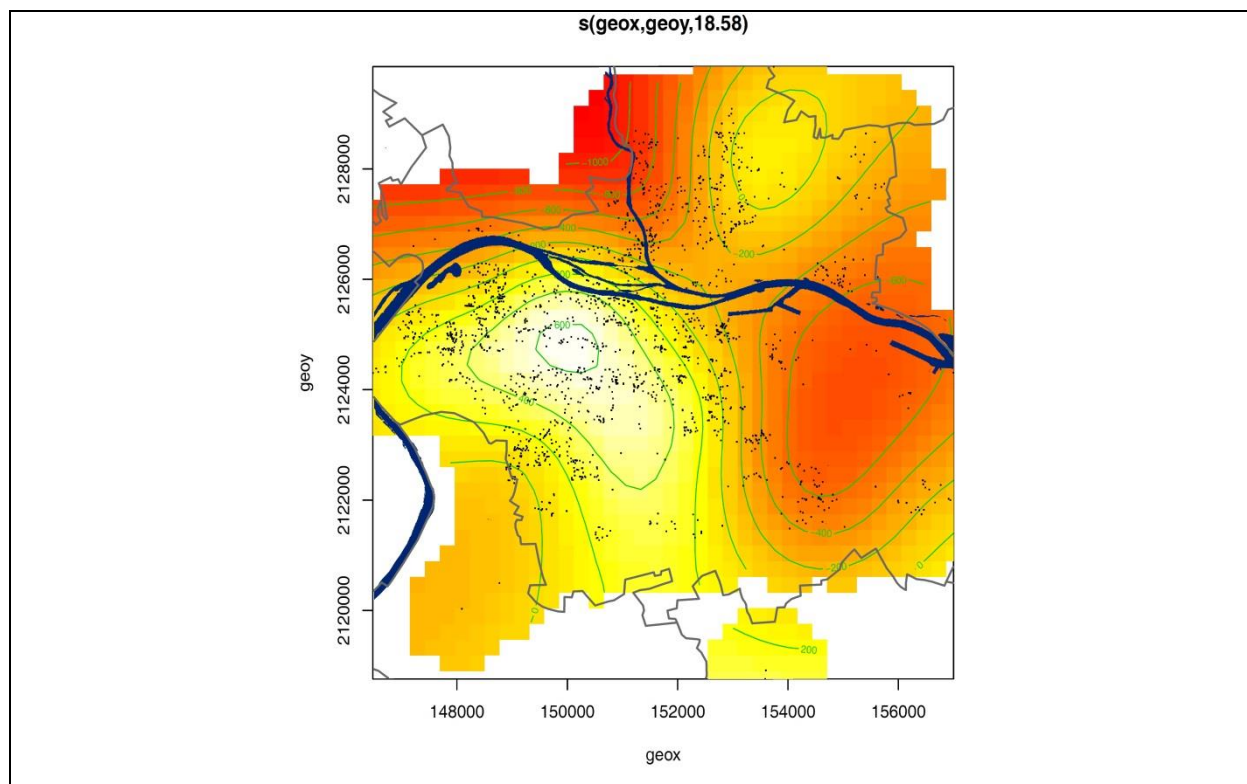
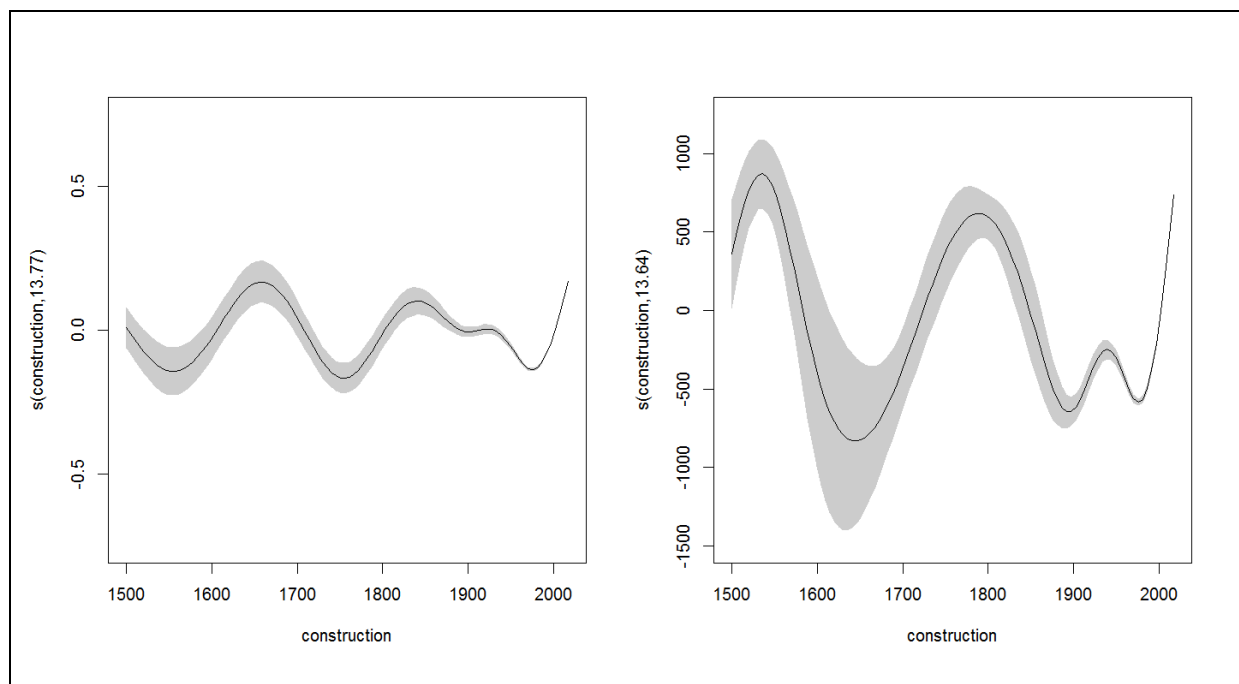


Figure 3.A3: Spline for Building Year Variable in Rents and Sales (extended timespan, rents left)



4. Does 'clean' pay off? Housing markets and their perception of heating technology

Purpose – This paper aims to investigate on the role of distinct types of heating technology and their price impact in German residential real estate markets, considering a wide range of other housing market determinants. We aim to test and to verify specifically, whether the obsolescence of heating technology leads to a significant price discount and whether higher technological standards (and environmental-friendliness) come with a price premium on the market.

Design/methodology/approach – We create housing market models for rental and sales segments by constructing Generalized Additive Models (GAMs) with explicit multi-layered spatial components. To elaborate a profound and contemporary answer using these models, we perform large-sample regression analyses based on more than 400,000 observations covering German residential properties in 2015.

Findings – First and foremost, the heating system indeed shows significant explanatory importance for measuring housing rents and purchasing price. Secondly, we find that it makes a difference whether clean 'green' technologies are implemented or whether 'brown' systems with obsolete technology or fossil energy sources is on hand. Ultimately, we conclude that while low energy consumption indeed comes with a price premium, this needs to be interpreted together with the property's heating type, as housing markets seem to outweigh the 'green premium' by 'brown discounts' if low energy consumption figures are powered by a certain type of heating technology system.

Research limitations/implications – Aside of a possible omitted variable bias, the main research limitation is constituted by the integration of asking prices in the analysis, as actual transaction prices are not systematically transparent on national level in Germany. Limitations are discussed at the end of the paper.

Practical implications – This work supports investors who face the challenge of making environmental- and energy-related decisions as well as appraisers who deliver financial fundamentals for such. Thirdly, the paper supports both asset managers as well as investment strategists in argumentation pro environmental investments beyond all ecological necessity.

Social implications – This paper contributes to the current discussion on climate change and the eclectic role of real estate in this context. We deliver evidence on pricing effects as a measure of socioeconomic acceptance of progressive heating technology and environmental-friendliness as an imperative of 21st century societies.

Originality/value – This is the first study on 'green premiums' or 'brown discounts' that includes heating technology as a potential and distinct driver of value and rents. It is a contemporary contribution and delivers original information on the quantitative impact of contemporary and anachronistic technology in heating to researchers as well as investors and appraisers.

4.1. Introduction

Over the last two decades, research on additional property values and rents, which were generated or empowered by a high standard of green features, has attracted increased research interest. In particular, high energy efficiency or good scores from sustainability certificates were identified as possible drivers of a property's financial performance (*Miller, Spivey and Florance, 2008*). And indeed, this financial impact is not only limited to a cost-reducing effect regarding operating costs of the property (which would depict a typical benefit on the tenant's side), but also refers to the net rent as direct income of the owner, which could be increased by energy efficiency measures. Also, in terms of property values or sales prices (a logical continuation of the rental situation), this positive effect on market prices was observed.

In this context, this paper aims to extend evidence on these 'green premiums' by

- (1) performing a large-sample hedonic study on German residential real estate, incorporating more than 140,000 contemporary observations from the sales and 260,000 contemporary observations from the rental market,
- (2) implementing a logic for the identification of properties in urban centers to eventually account for the specific price situation arising from the lifestyle and image of urban centers in contrast to other areas,
- (3) raising and answering the question, if the additional consideration of the type of heating technology installed in the property leads to a significant result and explanatory improvement of the model, compared to previous approaches.

The study finds itself within a context and history of literature that has aimed to isolate the financial effect of high energy efficiency in the property market. The paper aims at broadening the understanding of a 'green' property beyond mere energy efficiency by incorporating types of heating technology and thus, representing a more comprehensive view on residential buildings and their ecological footprint.

4.2. Literature Review

In the context of **residential real estate**, early contributions on U.S. markets have confirmed a positive impact of energy efficiency and fuel types on property prices. Fundamentally, *Halvorsen and Pollakowski, 1981*, constructed theoretical models and ran empirical analysis that proved how changes in fuel prices significantly impacted house prices eventually. With fuel

prices being only one possible determinant of energy costs, *Gilmer, 1989* made use of nascent energy performance certificates, or specifically a previous system of energy rating systems, by investigating the impact of this market transparency, finding that energy labelling could moderately shorten search efforts and search time necessary to identify appropriate residential properties.⁷ The author admits, however, that the impact could have been clearer and stronger in a study that exceeded the barely diverse sample market of Minnesota. *Nevin and Watson, 1998* confirmed that housing markets incorporate an incremental value to energy-efficient homes, which reflects a present value of annual fuel savings based on an expected capitalization rate of 4 % to 10 %. The study, however, supposes a certain linearity in consumption patterns, while there may be a certain “bottom-line” consumption and probably a ceiling in consumption levels. Also, the connection between fuel savings were not ultimately related to the number of household members, so that smaller households would be suggested to realize capitalization gains, while savings in annual expenditures were not generated technologically. In a study on California homes sold between 2000 and 2009, *Hoen, Wiser, Cappers and Thayer, 2011* found evidence that the volume of an on-site photovoltaic energy system has positive marginal impact on home sales prices that ranges between 3.90 US dollars and 6.40 US dollars per installed watt. However, photovoltaic is not an adequate comparable to the approach in this study, as photovoltaic has the main purpose of producing electricity – contrary to, for instance, thermal solar systems that aim at providing heating to homes. For the case of Ireland, *Hyland, Lyons and Lyons, 2013* found evidence that energy efficiency comes with a positive impact on purchasing prices as well as residential rents, whereas the sales market shows a stronger effect. In an extension towards a cross-market analysis, they find that energy ratings play a stronger role and amount higher if the general market conditions are worse. Based on data from the IPD database, *Cajias and Piazzolo, 2013* have established a more portfolio-oriented approach for measuring green property price premiums c.p. and isolated that energy-efficient buildings in Germany showed up to 0.76 EUR higher rents per square meter and increased returns of up to 3.15 % in comparison to energy-inefficient assets. Also, the total return (TR) of the property appeared positively affected by energy efficiency: A one percent decrease of energy consumption could be linked to a 0.015 % increase of the TR, aside of 0.08 % higher rent prices and 0.45 % increase in market value. *Fuerst et al., 2015* have analyzed a data set of over 300,000 housing units that were sold repeatedly between 1995 and

⁷ Similar studies comprise *Lacquatra, 1986*, who has shown that the energetic standard of a property, measured by the Thermal Integrity Factor (TIF) as a proxy, is positively correlated to the transaction price. *Dinan and Miranowski, 1989* produced comparable findings and quantified that one dollar in energy costs saved would c.p. multiply to 11.63 US dollars of increased sales transaction price in their sample.

2012. They investigated whether energy performance ratings are reflected in sales prices and indeed found a positive relationship between a dwelling's energy efficiency rating and its transaction price per square meter. The applied model incorporated property characteristics such as the building type and found that top-rated properties generate a 5 % premium c.p., and even a 'good' standard (rating class C) still generates a 1.8 % premium in the purchasing price. Performed by *Fuerst, Oikarinen and Harjunen, 2016*, a comparable study covering Helsinki delivered a slightly lower energy efficiency premium at approximately 1.3 % considering several control variables. While green signaling effects could be confirmed, they did not ultimately result in accelerated sales. *Cajias, Fuerst and Bienert, 2016* have analyzed a data set of 570,000 observations covering the time span between 2013 and 2015 for German residential rental markets. The analysis covered the equipment of the property as well as its overall condition as control variables. As the excessive data scope caused superior computational requirements, sub-samples of top 7 city locations as well as secondary markets were created. For this sub-sample, the effect of energy efficiency turned out to be a lot less clear and more unexpected than in the secondary markets. However, the existence of a green premium for German housing markets could be generally confirmed. Also, *Mense, 2016* performed analysis in a comparable direction covering German real estate. However, no clear results on the role of local gas prices or regional climate were identified. Especially, different fuel types did not deliver a consistent picture towards price premia from the data set used.

The overall picture of existing research results is also confirmed in the **commercial real estate segments**; as further evidence in this context, *Eichholtz, Kok and Quigley, 2010* show that Energy Star labeled properties, which belong to the top 25 percent of the most energy-efficient buildings, achieve a rent level of 2 % to 3 % above the level of comparable regular offices. In terms of transaction prices, even higher premiums were observed at 13 % to 16 %, proving a strong tendency for capitalization of energy savings. *Fuerst and MacAllister, 2011* performed a cross-sectional analysis to identify the effect of energy performance ratings on appraised values, rents and yields of 708 commercial properties in the UK. The hedonic regression model incorporated additional market factors such as the vacancy rate, the unexpired lease term and the tenant's credit risk in order to isolate the effect of the EPC rating. A significant relationship could, however, not be confirmed for the overall sample, which might be due to the fact that energy efficiency did not yet have the relative importance of today (i.e. political as well as social awareness in a property context). *Newell, MacFarlane and Walker, 2014* compare a portfolio of approximately 200 green office buildings in Australia with a set of non-green

properties through hedonic regression in order to identify the effect of better NABERS⁸ or GreenStar ratings (both are built environment rating schemes) on office values and rents. In this sample, premiums are most evidently at the top end of the ‘greenness scale’, although also discounts for poorer energy performance (‘brown discount’) are significant.

In addition to the literature discussed before, the following table gives an overview of selected related studies and specifically the variables applied in the underlying models.

Table 4.1: Overview of Literature and included regression variables

Author (Year)	Estimated Variable(s)	Explaining Variables
Fuerst and McAllister (2011)	Rent	Building certification result, size, net lease, number of stories, site area, building age class, longitude, latitude, property class, submarket controls
	Sales price	Building certification result, size, number of stories, size, site area, building age class, longitude, latitude, property class, market strength, submarket controls
Wameling (2010)	Value Change	Economic variables (sales price, land value, general average land price, intrinsic property value, building year, date of purchase, remaining useful life, year of substantial change in construction, value adding or reducing factors) Property variables (property type, orientation, roof type, fit out of attic, basement, building quality, heating, windows and doors, walls/facade, final energy demand, heat energy demand, primary energy demand, degree of compactness)
Leopoldsberger et al. (2011)	Mean rent	Net floor space, quality of the building, existence of an elevator, air condition, maintenance costs, energy costs, year of entry into database, city, district, heat energy demand, year of construction, general condition, floor size, terrace, balcony, garage, parking lot, time index
Chegut, Eichholtz and Kok (2014)	Rental price	BREEAM-certified, certified building supply, rent contract features (lease term, days on market, rent free period), quality characteristics (rental unit size, story, building age class, amenities, renovation status), distance to train, distance to road
	Sales price	BREEAM-certified, certified building supply, investor type, quality characteristics (rental unit size, story, building age class, amenities, renovation status), distance to train, distance to road
	Sales price	Green certification, quality class, building size, building age class, renovation status, story, amenities, public transport

⁸ National Australian Built Environment Rating System

Aroul and Hansz (2012)	Sales price	Greenness type, size, number of bedrooms, number of baths, pool, building age, location, foreclosure of property, association membership, quarter and year of sale
Reichardt et al. (2012)	Rent	Certification label, building age, years since last renovation, number of stories, rentable building area, total area of land, building type, vacancy rate, regional unemployment rate, regional change in office stock, regional vacancy rate
Cajias and Piazzolo (2013)	Total return, rent price, market value	GDP per capita, energy consumption/EPC category, management costs, distance to CBD, latitude, longitude, usable area, building age, location parameter, year
Laquatra (1986)	Selling price	Size of lot, finished floor area, unit type, thermal integrity factor, median house value in census tract, school district expenditures per pupil, mean journey time to work, distance from interstate ramp
Dinan and Miranowski (1989)	Implicit selling price	Number of bedrooms, number of bathrooms, room types present, floor area, lot area, basement, general equipment, air conditioning, garage, property age, fuel costs adjusted for national climate, regional income, distance to CBD
Hyland, Lyons and Lyons (2013)	Log rental rate, (all properties/ BER energy-rated properties), log of sales price (all properties/ BER properties) BER= building energy rating	A categorical variable for each BER from A1 (most efficient) to G (last efficient), sub-ratings grouped by letter (F and G grouped together), date at which the legislation came into effect on the mandatory labelling of properties offered for sale/ rental, House type (terraced/semi-detached/detached/apartment/bungalow), property is in a new development or not, number of bedrooms and bathrooms, and number of single rooms, 35 regional dummies, located in a rural area, quarter, year, continuous time variable

As this composition of variables and the overall review of literature reveals, there is a research gap in the field of sustainable real estate research and ‘green pay-off’ studies as the heating technology of the property has not been systematically taken into account nor has it been made the core object of investigation.⁹ We intend to close this gap and therefore derive the research question whether the consideration of heating technology standards affects the regression results regarding a potential green premium from energy-efficiency and which price impact

⁹ Also, structural price differences between urban and rural areas were not systematically considered in all studies and only approximated by ‘distance to CBD’ or the underlying land prices. In this study, we will suggest and incorporate an alternative for that based on structural land use data from a European Union program. This depicts a more direct approach that can also handle non-radial distance structures of urban land use patterns.

can be assigned to heating technology and to different levels of technological progressiveness therein.

Why heating technology could matter, too

In German housing markets, the role of energy consumption and costs and its financial handling is diverse: on the residential sales market, of course, owner-occupiers bear operating costs – including heating costs – themselves. Looking at rental housing, two general contractual constellations are possible: in one scenario, a gross rent is agreed on; thereby, the tenant pays a flat fee and all operating costs are covered. In this scenario, energy savings are completely collected by the investing landlord. However, this scenario is a (significant) minority, as most landlords spare the risk of paying for unreasonable energy consumption by the tenants or the risk of price increases in operating expenses over time. The more common scenario is that tenants perform monthly advance payments, which are then accounted for once a year. Excess costs are then paid for by the tenant, while excess funds are then paid out to the tenant. This comes with an inherent incentive to save energy for the tenant. At the same time, energy efficiency improvements – usually paid for by the investing landlord – benefit the tenant by reduced operating costs. In order to solve this split-incentive problem, German legislation has introduced regulations that enable the recovery of investment costs towards energy-efficiency, thereby increasing the net rent paid by the tenant (“legal green premium”). The question arises, whether the reimbursement of these investments is actually and empirically visible in both net rents as well as purchasing prices, eventually.

Most of the studies discussed before refer to similar market constellations and mainly incorporated fundamental property characteristics and energy consumption data as explanatory variables for an estimation of the respective ‘green premium’. However, underlying data sets typically do not allocate information on the respective type of heating technology. Yet, this aspect may be of specific interest in property transactions both on the sales as well as the rental market for several reasons:

Conventional or fossil heating technology may come with a negative outlook for future demand and sustainability. This is in particular observable by the fact that although the consumption horizon for oil or gas reserves may be determined by decades, already today

several nations have declared their intention to become a lot more independent of these energy sources.¹⁰ Germany and its energy shift concept ('Energiewende') is one of these countries.

Secondly, energy consumption levels alone are a very condensed perspective on sustainability, as this variable does not appreciate the fact that sustainability may arise in the building envelope or the heating system separately. In addition, using energy consumption information from energy performance certificates does not necessarily ensure comparability between properties, as user/tenant behavior may impact these levels in residential certificates.

In addition, 'green' heating technology features a shorter learning curve in terms of technological development and application compared to fossil heating technology, which already had decades of time to evolve. This leads to a situation where deciding in favor of modern technologies in a property typically comes with higher investment costs for the owner compared to a conventional, fossil heating system. At the time of sale, it should be expected that the owner tries to recover these higher investment costs from a potential buyer or a tenant over time.

And ultimately, the concept of social responsibility has received high recognition and currentness, not least because of public pressure from the Paris climate agreement and international ambitions to conserve resources for the next generations. Renewable energy sources and low-emission heating may therefore thoroughly create financial benefits on property markets. Existing evidence has already suggested an altering demand-side behavior on housing markets. However, the role of 'green' or obsolescent heating technology appears still under-researched in this context.

Therefore, our study is based on an individually adjusted data set that compiles the commercial information and the property characteristics with a variable on the urban vs. rural land use pattern of the micro location as well as the type of heating technology that is implemented in the property.

As consequence of the considerations before, we formulate the hypothesis that aside of higher housing prices from low energy consumption there is also a difference in the price structure considering the obsolescence of certain heating technology, especially fossil heating systems (which we expect to quote at a 'brown discount'). We also expect that promoting the global

¹⁰ During the 2016 United Nations Climate Change Conference in Marrakech, 47 countries of the "Climate Vulnerable Forum" declared their intention to produce even a 100 % of their domestic energy using renewable energy sources. These nations are mainly developing countries.

efforts for sustainability comes with financial benefits ('green price premium' for properties that are fueled by 'green' heating technology). In the following section, we will analyze what is actually reflected in the market prices.

4.3. Empirical analysis

Methodology

In order to receive respective evidence, we construct a multivariate regression model to isolate and to control for the effect of several driving impact factors on asking prices of landlords and sellers. The model is set up as a Generalized Additive Model (GAM), as we assume that the market-related behavior patterns may not always be of pure linear nature and GAM can reflect this non-linearity. Our GAMs follow the fundamental form

$$Y = f_0 + \sum_{j=1}^p f_j(X_j) + \varepsilon$$

where errors ε are independent of X_j , $E(\varepsilon) = 0$ and $\text{Var}(\varepsilon) = \sigma^2$ and f_j describes univariate smooth functions, one for each variable included, in order to account for possible non-linearity.

We incorporate property rent or property value as Y and functions of several (financial and technical) property characteristics as well as geographic and geo-based information as explaining variables. Therefore, we estimate:

$$\begin{aligned} \text{Log}(\text{SalesPricePerSQM}) = & c_0 + \partial_1(\text{heatingtype_class}) + f_1(\log(\text{floorspace})) + f_2(\text{numberofstories}) \\ & + f_3(\text{constructionyear}) + f_4(\log(\text{energyconsumption})) \\ & + f_5(\text{numberofrooms}) + f_8(x_y_coordinates) + \partial_2(\text{balcony}) \\ & + \partial_3(\text{listed_building}) + \partial_4(\text{quality_of_equipment}) + \partial_5(\text{urban_center}) \\ & + \partial_6(\text{propertytype}) + \partial_7(\text{federal_state}) + \varepsilon \end{aligned}$$

$$\begin{aligned} \text{Log}(\text{RentPricePerSQM}) = & c_0 + \partial_1(\text{heatingtype_class}) + f_1(\log(\text{floorspace})) + f_2(\text{numberofstories}) \\ & + f_3(\text{constructionyear}) + f_4(\log(\text{energyconsumption})) \\ & + f_5(\text{numberofrooms}) + f_8(x_y_coordinates) + \partial_2(\text{balcony}) \\ & + \partial_3(\text{listed_building}) + \partial_4(\text{quality_of_equipment}) + \partial_5(\text{urban_center}) \\ & + \partial_6(\text{propertytype}) + \partial_7(\text{federal_state}) + \varepsilon \end{aligned}$$

where

c_0 is the intercept, f_i depicts functions to reflect non-linearity, ∂ depicts linear or dummy variable

$\log(\text{floorspace})$ = floor space in square meters (logarithmic)

numberofstories = number of floors in the building

constructionyear = year of construction

energyconsumption = final energy consumption in kWh per square meter and year

numberofrooms = total number of rooms

$x_y_coordinates$ = x, y coordinates of the property location

balcony = whether the property has a balcony

listed_building = whether the property is a listed building and therefore of historic substance

heatingtype_class = class of the heating system type (green/standard mix/brown)

$\text{quality_of_equipment}$ = standard of property fit-out

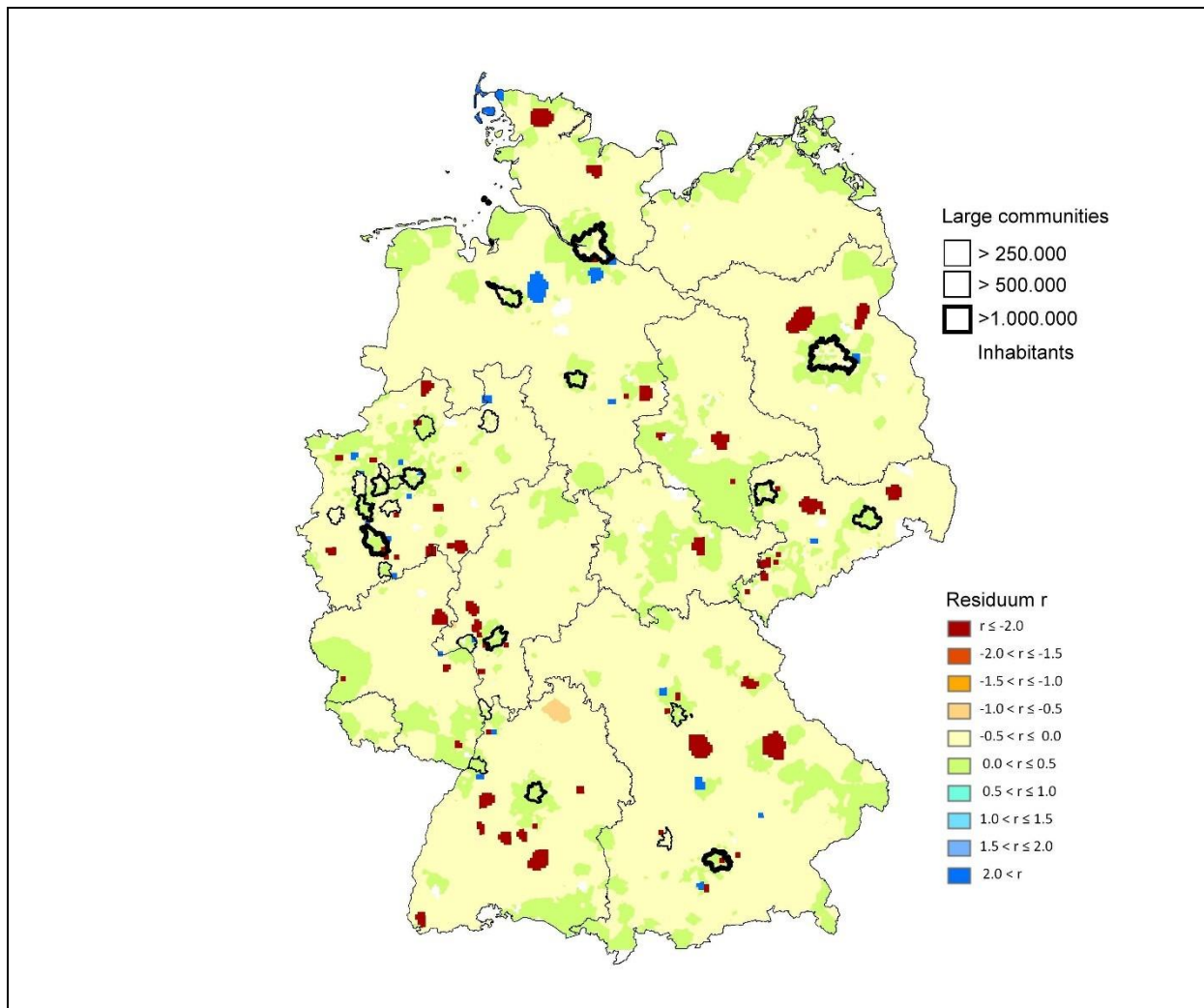
urban_center = whether the property is located in an area that is subject to centrally urban use per the CORINE logic

propertytype = type of the property (house vs. apartment)

federal_state = the applicable from 16 federal states in Germany

In addition to performing the estimates, we analyze the data for several statistical phenomena that might be expected given the scope and extent of the data as well as its timeline. This analysis comprises, but is not limited to, questions of spatial autocorrelation and heteroscedasticity of error terms. And while the data shows the expected variations in statistical dispersion, we found that spatial autocorrelation is very limited and does not happen systematically across the whole sample. Most importantly, we can confirm that spatial autocorrelation specifically not occurred excessively in the big city regions of Germany and also the majority of the rest of the country did not show exaggerations in similarities between nearby observations.

Figure 4.1: Residual Analysis – Spatial Autocorrelation within the Data Set



Data

In our estimates, we included residential properties (apartments and houses) in the Federal Republic of Germany, which were advertised for lease or sale in 2015 on the web platform Immobilienscout24. The total underlying data basis for that year comprises 3.2 million observations. However, only a small share of these did actually provide information on the energy consumption as well as all other variables required by the model. Therefore, the total sample eventually comprised 408,000 observations.

The observations comprised financial information (rent or sales prices), property characteristics and location information – including the heating type installed – and location information. Descriptive statistics of all explanatory variables included are listed below.

Table 4.2: Descriptive Data Statistics: Rental Housing Model

Variable	Min	1 st Quartile	Median	3 rd Quartile	Max	Mean
area (sq.m.)	9.0	56.0	72.0	94.4	938.0	79.6
# of stories	1	2	3	4	45	3.423
Construction Year	19	1955	1974	1996	2019	1969
Energy Consumption (kWh/m²a)	0.01	85.50	119.0	153.0	400.0	123.0
Number of rooms	1	2	3	3	100	28.87
Distribution of Categorical Variables						
HeatingType_Class	Brown 2.52 %	StandardMix 87.98 %	Green 9.50 %			
Balcony	Yes 67.06 %	No 32.94 %				
Listed Building	Yes 1.18 %	No 98.82 %				
Quality of Equipment	Simple 1.38 %	Standard 51.43 %	Sophisticated 43.02 %	Luxury 4.17 %		
Urban_Center	Yes 7.76 %	No 92.24 %				
Property Type	House 6.09 %	Apartment 93.91 %				
Federal State	Baden-Wuerttemberg 8.56 %	Bavaria 12.79 %	Berlin 10.40 %	Brandenburg 2.41 %	Bremen 0.67 %	Hamburg 2.24 %
	Hesse 8.68 %	Mecklenburg-Vorpommern 9.67 %	Lower Saxony 5.27 %	Northrhine-Westphalia 31.35 %	Rhineland-Palatine 3.23 %	Saarland 0.18 %
	Saxony 7.09 %	Saxony-Anhalt 2.27 %	Schleswig-Holstein 2.67 %	Thuringia 1.22 %		

Table 4.3: Descriptive Data Statistics: Residential Sales Model

Variable	Min	1 st Quartile	Median	3 rd Quartile	Max	Mean
area (sq.m.)	12.0	76.0	109.6	148.0	962.0	119.4
# of stories	0	2	3	4	30	3.13
Construction Year	1015	1964	1987	2010	2017	1979
Energy Consumption (kWh/m²a)	1.15	68.0	112.0	158.0	400.0	121.8
Number of rooms	1	3	4	5	100	4.09
HeatingType_Class	Brown 10.80 %	StandardM ix 80.45 %	Green 8.75 %			
Balcony	Yes 45.26 %	No 54.74 %				
Listed Building	Yes 1.22 %	No 98.78 %				
Quality of Equipment	Simple 2.21 %	Standard 61.52 %	Sophisticat ed 32.62 %	Luxury 3.65 %		
Urban_Center	Yes 9.04 %	No 90.96 %				
Property Type	House 43.70 %	Apartment 56.30 %				
Federal State	Baden- Wuertte mberg 12.15 %	Bavaria 15.53 %	Berlin 10.69 %	Brandenbu rg 2.75 %	Bremen 0.51 %	Ham- burg 19.25 %
	Hesse 8.61 %	Mecklenbu rg-Vor- pommern 0.93 %	Lower Saxony 6.89 %	Northrhin e-West- phalia 25.15 %	Rhinelan d-Pala- tine 6.25 %	Saarlan d 0.66 %
	Saxony 2.83 %	Saxony- Anhalt 0.70 %	Schleswig- Holstein 3.67 %	Thuringia 0.75 %		

We performed data optimization in terms of excluding several implausible entries from the total data stock, according to a set of clear rules and patterns. This optimization was necessary in order to account for the fact that the information provided was put in by the users

themselves and due to these free-hand inputs, respective values may have been entered mistakenly.¹¹

In addition to the raw information provided, we also enriched the given data set in terms of location and land use. Specifically, we added *urban_center* as a control variable to isolate price differences between locations with specific “urban usage” and other areas. While the pure distinction between rural areas and urban area is already contained in the x-/y-coordinates included, the urban usage identifies urban central districts, which enables the analysis of average price premia for the specific status of residing in an urban center in general, independent of cardinal directions. For the identification of these urban centers amongst the given data, we allocate spatial information to each data line using information from CORINE Land Cover, an EU-initiated project on gathering land use information. This brings the advantage that the study can reflect non-radial CBD patterns and do not have to approximate the urban land use by price information or other indirect information. As the analysis is performed on the basis of square meter rents and prices, the joint integration of houses and apartments comes with the advantage of direct comparability in terms of the price impact from the two major types of housing on the market.

And ultimately, we created three baskets amongst all properties to distinguish the type of heating system used. The first group depicts the benchmark group containing those properties where no distinct information on specifically good or bad quality of the heating ecology was given. This group comprises properties, where houses and apartments were advertised to feature heating fueled with a standard or rather unspecific fuel mix. We regard this group as the reference group in order to isolate the market reaction pattern toward properties that feature more specific information. These properties are organized in the two other baskets, where those properties subsumed that are advertised with highly green heating features (e.g. pellet heating or thermal solar systems) and therefore explicitly apply ‘green technology’ or advertised to contain fossil or even obsolete heating systems (such as coal or oil heating) and are therefore considered to apply obsolescent technology. Through this segmentation, we will be able to answer which effect can be associated with the explicit offering of ‘green’ or ‘brown’ heating technology. The segmentation is summarized in the table below.

¹¹ For instance, offers with purchasing or rent price of 0 € or 1 € were excluded. Other sample selection logics refer to implausibly high room numbers or living areas of the property offer, excessive energy consumption, the year of construction or the actual geographic location. In the rental model, the original $n = 761,854$ was reduced to $n = 266,583$ and in the sales model, it was reduced from $n = 312,087$ to $n = 141,859$ through the optimization.

Table 4.4: Classification of Heating Technology

Heating Technology Class	Elements (selected)	Reasoning
Green	<ul style="list-style-type: none"> • Combined Heat and Power Unit (CHP) • Wood Pellet Heating • Thermal solar heating • District Heating System • Thermal Heat Pumps 	This basket of properties specifically advertises progressive technology with the clear majority being powered by renewable energy sources. As such, it incorporates low-emission or emission-free heating observations as well as wood with low amounts of fine particles.
Standard	<ul style="list-style-type: none"> • Central Heating Technology • Underfloor Heating • Gas-fueled Heating • Properties without specifically progressive or conventional heating technology advertised 	This basket of properties does not advertise any specifically progressive or eco-friendly heating technology and depicts a set of typical floor- or property-supplying equipment, which is typically based on standard technology or an externally given energy mix. Also, we add gas-based heating technology, which despite technological progress of other systems is based on a longer lasting energy source than, for instance, oil-based technology.
Brown	<ul style="list-style-type: none"> • Room-based heating • Oven Heating Technology • Oil-fueled heating of any technology 	This basket of properties advertises specifically obsolescent technology such as room-based oven heating or oil-fueled heating systems. Despite its use of renewable energy sources, we also include oven heating with wood billets, as its emissions of fine particles are more than double as high as with wood pellet heating systems, while for instance gas heating basically causes zero fine particle.

Results

Our study finds that properties that were specifically advertised as including ‘brown’ heating technology were offered for sale at a discount of approximately 4.23 % c.p. in comparison to those properties that were offered with heating technology that depends on the regional standard energy mix. In the rental market, this brown discount quotes lower at – 2.44 % c.p.

Contrary to that, properties with 'green' heating technology were offered at an attributable sales price premium of 3.06 % c.p. in comparison to housing that was offered without specific 'green' or 'brown' heating technology. In rental housing markets, this 'green premium' amounts to 2.42 % c.p. These figures are found to be highly significant at 0.1 % level.¹²

Figure 4.2: Price effects of heating technology in sales and rental market

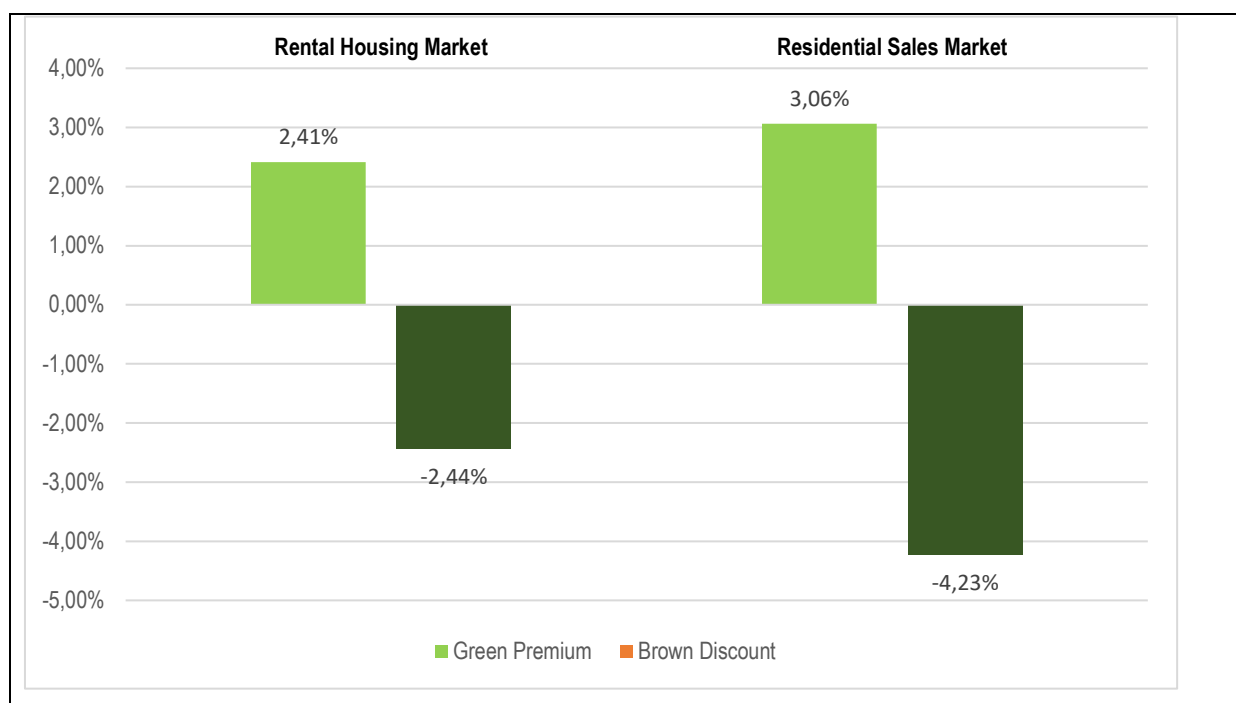


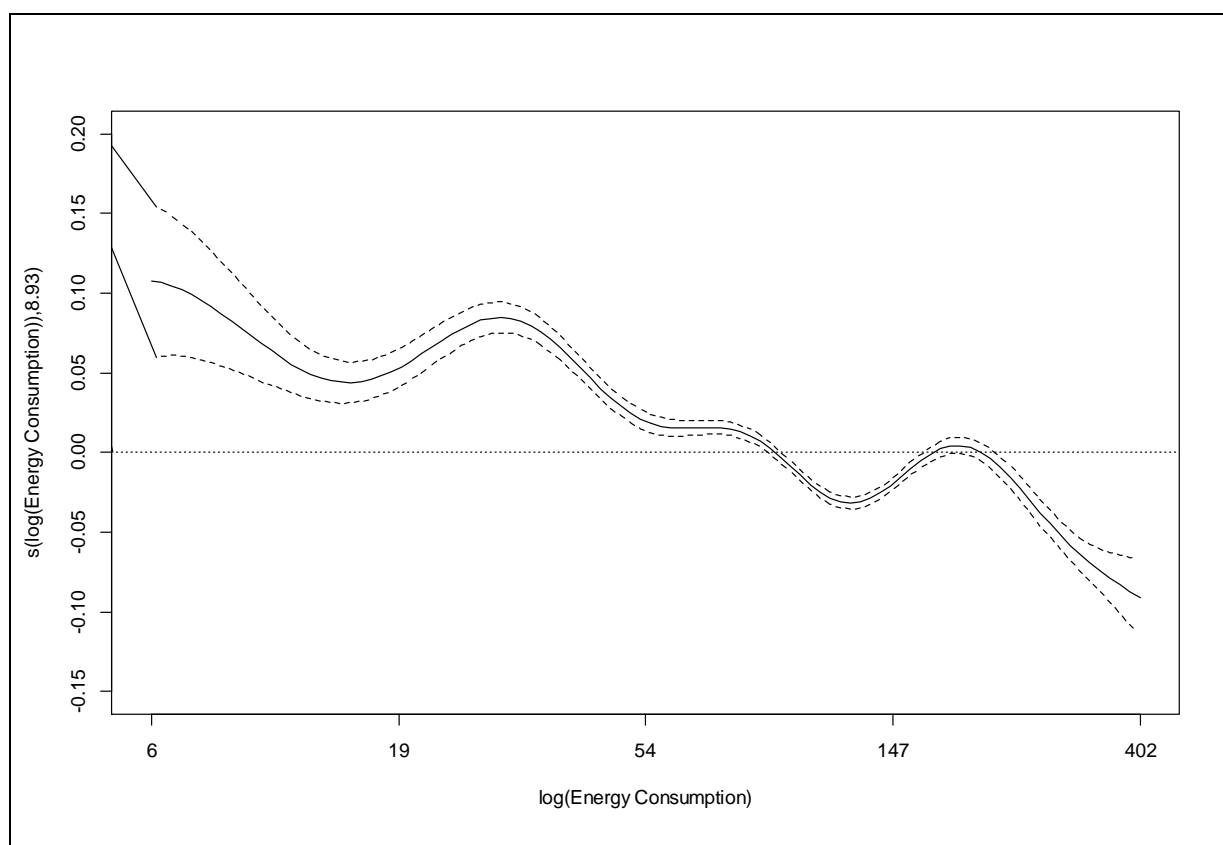
Table 4.5: Output of Price Impact by Heating Technology

(Sales) Brown Heating Technology	-0.042286	0.004635	-9.123	< 2e-16 ***
(Sales) Green Heating Technology	0.030613	0.003015	10.154	< 2e-16 ***
(Rents) Brown Heating Technology	-0.0243893	0.0029173	-8.360	< 2e-16 ***
(Rents) Green Heating Technology	0.0241706	0.0016134	14.981	< 2e-16 ***

¹² Significance levels in Generalized Additive modelling is subject to specific considerations, as they typically come with a downward bias, cf. Wood, 2013. However, due to the large sample size included in the study, high levels of confidence should be supposed nevertheless.

In terms of general energy efficiency and energy consumption levels, this study is in line with existing evidence and confirms the existence of 'green premiums' from low energy consumption figures. The following spline illustration shows the structural sales price pattern that can be attributed to the energy consumption level of the properties.

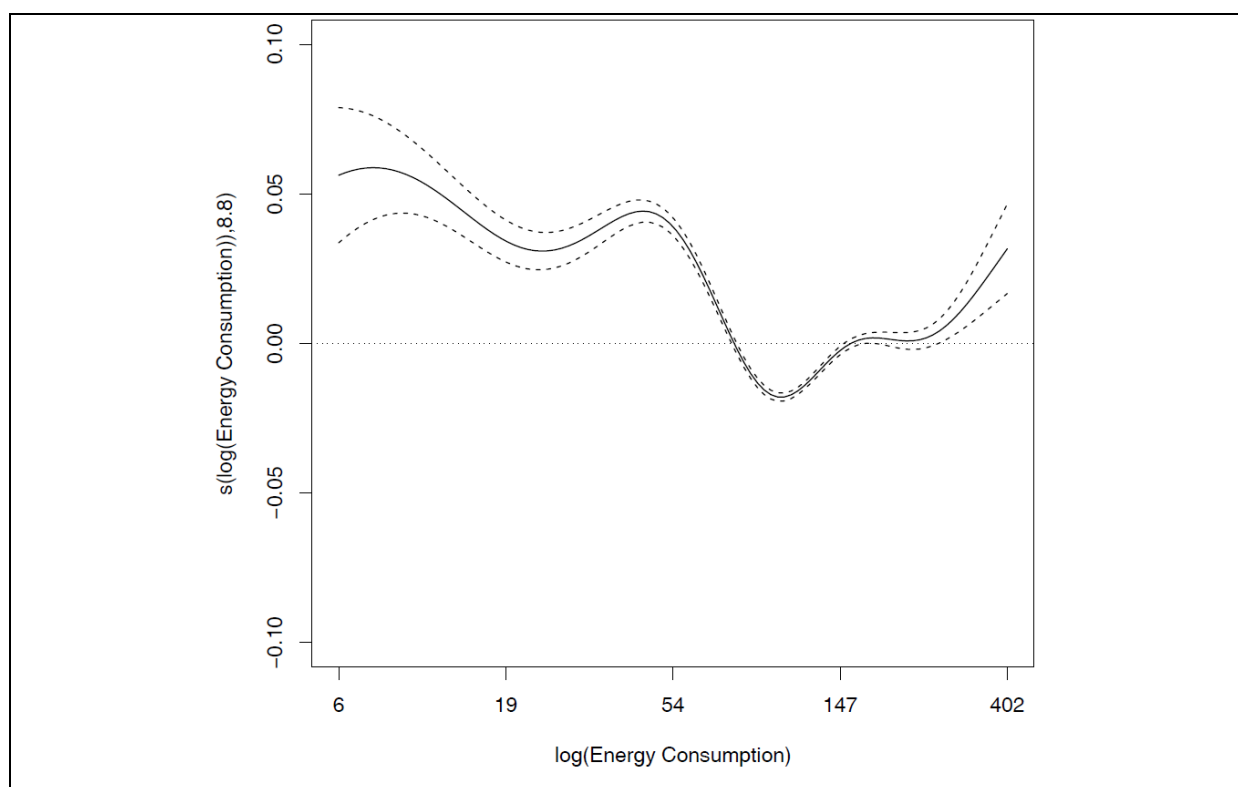
Figure 4.3: The Price Impact of Energy Consumption in Sales Markets



This pattern is significant at a 0.1 % level and illustrates how lowest energy consumption figures of less than 30 kWh per square meter and year come with a sales price premium of 5 to 10 % compared to the baseline of energy efficiency class C at between 75 and 100 kWh per square meter and year or lower. Simultaneously, extremely high energy consumption figures c.p. show a price discount of up to 10 %. We find that the market reaction in that sense appears very reasonable and rational investors do on average increase prices due to good energetic characteristics.

In that sense, the market seems to price in a superior energetic performance of a property. Something similar seems true for the rental market, as illustrated in the following graph, however the sales market's strict depreciation for poor energy efficiency cannot consistently be confirmed for the rental perspective. Apart from that, appreciation patterns for good energy efficiency are quite comparable to the insights gathered from sales markets.

Figure 4.4: The Price Impact of Energy Consumption in Rental Markets



Generally, the results of this study show higher 'green premiums' in sales markets than in rental markets. Also, the general level of sales price premiums appears higher than in comparable previous studies. But clearly, the confidence and distribution of the premium estimates show that the premium range increases especially in terms of buildings with extremely low consumption levels. Higher confidence, however, is observed in terms of 'brown discount' estimations regarding buildings with rather high energy consumption levels.

In addition to the energy- and technology-related aspects, we gather additional general insights into German housing markets from the integrated control variables that characterize the market structure by means of additional determinants.

Regional differences in the price structure are both controlled by the specific geographic micro location (given as x and y coordinates) as well as by assigning the respective state-level perspective as the macro market environment. While the macro environment accounts for effects that show common framework conditions (such as economic attractiveness on state-level, the North-South/Eastern-Western divide or the land transfer tax, which differs between the states), the consideration of micro location reveals regional price differences in connection to local differences on a very local scale of a few kilometers. The following illustration shows the spatial distribution of observations within this study on German housing markets as well as a heat map of the spatial effects in terms of sales prices.

Figure 4.5: Residential Sales Price Heatmap – Germany

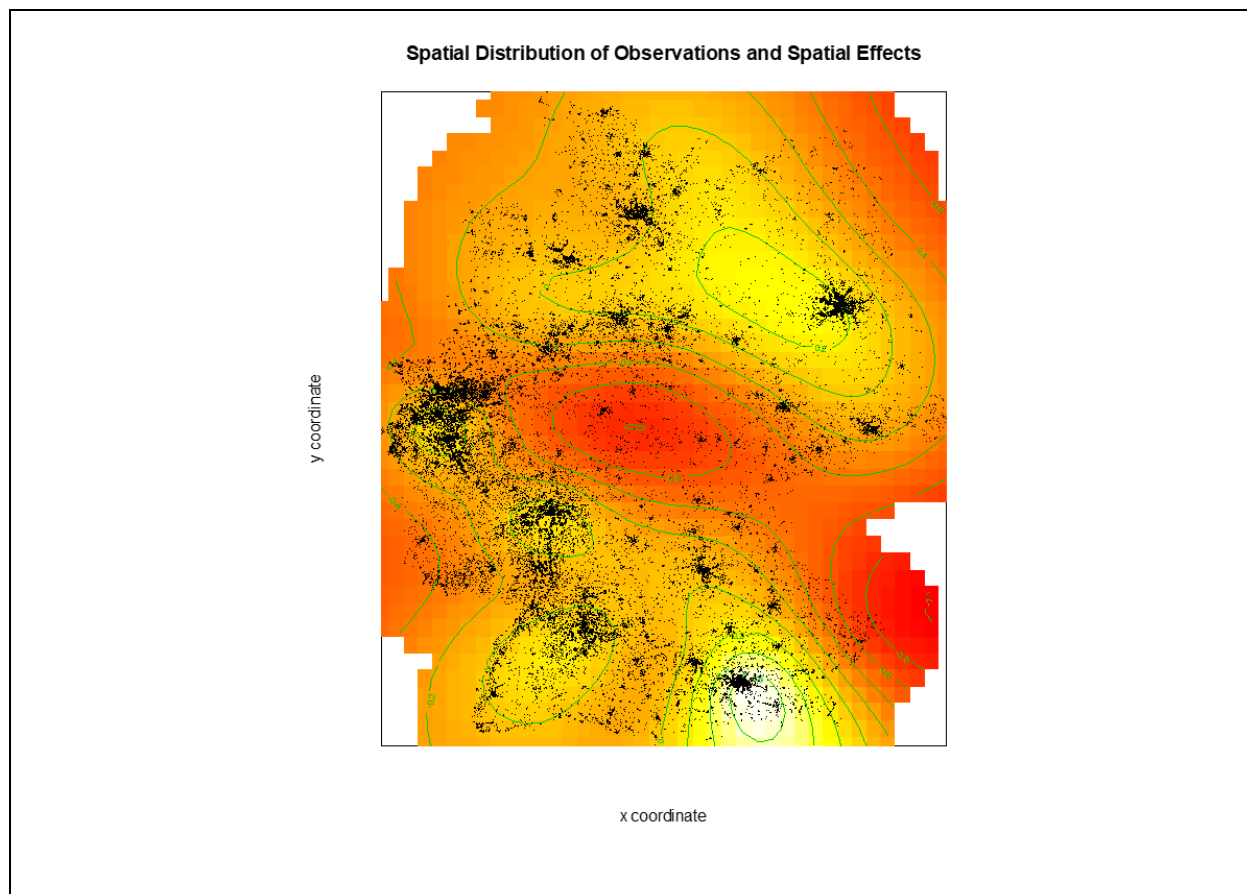
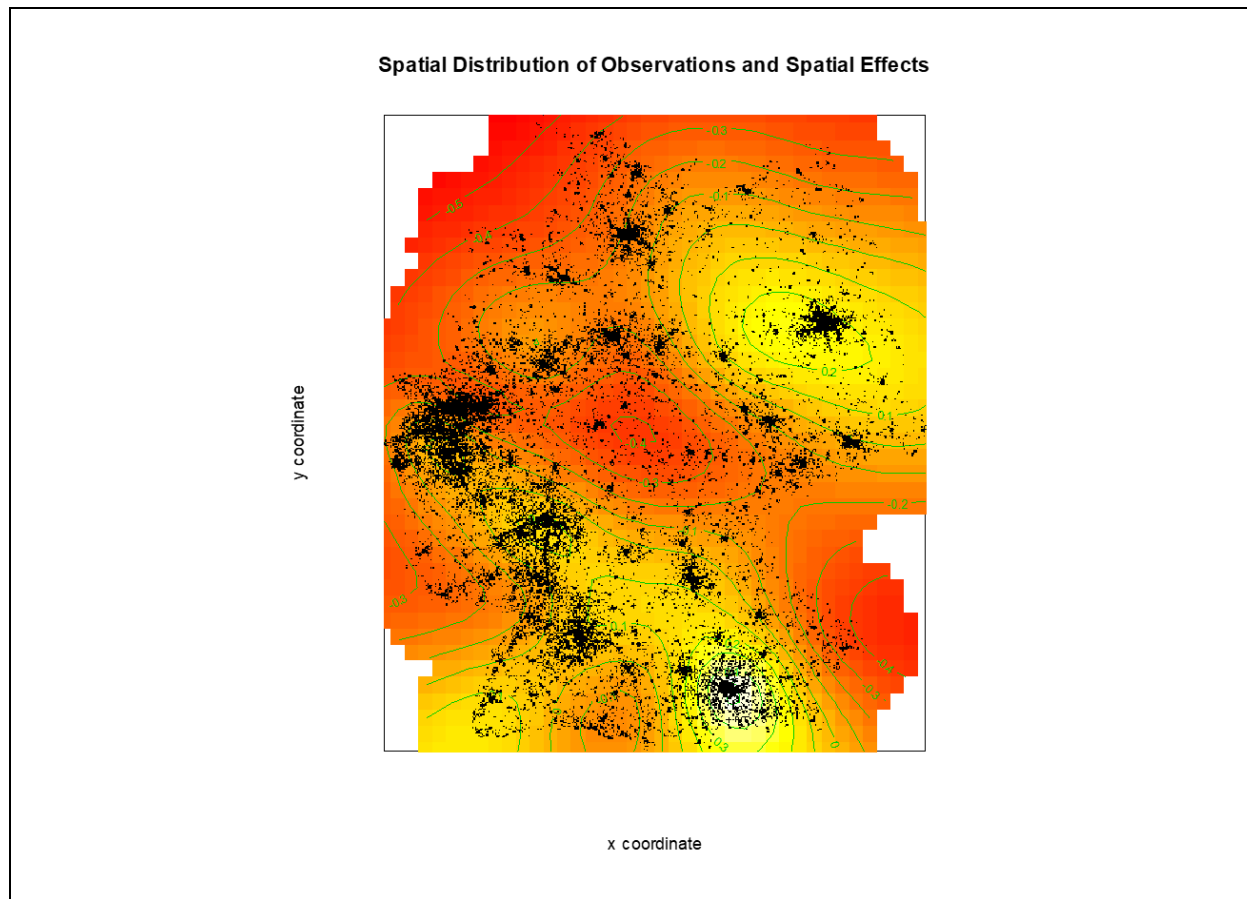


Figure 4.6: Residential Rent Price Heatmap – Germany



Regarding the state-level alignment, the following regional differences as impact of the macro location could be observed:

Table 4.6: Impact of Federal State Macro-Location on Housing Prices

	Sales Prices		Rental Prices	
State Name (transfer tax as per Jan 2017)	Price Premium/ Discount	Significance of Coefficient	Price Premium/ Discount	Significance of Coefficient
Hamburg (3.5 %)	+ 46.26 %	***	+ 43.74 %	***
Thuringia (6.5 %)	+ 7.50 %	***	- 4.44 %	***
Hesse (6.0%)	+ 4.40 %	***	+ 2.69 %	***
Berlin (6.0 %)	+ 2.19 %	statistically insignificant	- 17.26 %	***
Bavaria (3.5 %)	+ 1.36 %	statistically insignificant	- 11.38 %	***
Baden-Württemberg (5.0 %)	<i>Benchmark</i>			
North Rhine- Westphalia (6.5 %)	- 9.71 %	***	+ 0.00 %	Statistically insignificant
Schleswig-Holstein (6.5 %)	- 10.78 %	***	+ 13.77 %	***
Bremen (5.0 %)	- 15.27 %	***	+ 10.92 %	***
Saarland (6.5 %)	- 15.46 %	***	+ 4.86 %	***
Rhineland-Palatine (5.0 %)	- 17.40 %	***	- 10.86 %	***
Saxony (3.5 %)	- 25.71 %	***	- 28.89 %	***
Lower Saxony (5.0 %)	- 28.01 %	***	+ 3.70 %	***
Mecklenburg- Vorpommern (5.0 %)	- 37.15 %	***	- 19.95 %	***
Brandenburg (6.5 %)	- 38.01 %	***	- 39.07 %	***
Saxony-Anhalt (5.0 %)	- 67.17 %	***	- 38.64 %	***

The general picture regarding the state-level variation of property prices seems coherent with other sources, e.g. sociodemographic and property data from the *Federal Statistical Office, 2018*, including official housing statistics, with Southern states as well as single-city states (including Berlin) showing higher price levels than, for instance, the Eastern states of the former socialist republic. However, in terms of the quantification of price differences, these sources may show different figures. The reason for that is that official statistics typically evaluate the blank price differences without controlling for the full range of price-building determinants. The residual for

the impact of the respective state in this paper is therefore generally lower than in other publications.

We find a sales price premium for housing in urban areas of 16.99 % c.p. and a rental price premium of 9.51 % c.p., both statistically significant at 0.1 % level. Compared to houses, apartments are typically offered at a lower price per square meter with a statistically significant (***) difference of 10.14 % on sales and 10.75 % on rental markets. The building type-related price differences from sales markets are, therefore, very simultaneously reflected in rental markets. Properties that feature a balcony are offered at a 9.87 % c.p. sales price premium (4.80 % c.p. in rental markets) and listed properties show a sales price premium of 17.86 % (rents: 5.64 %) c.p. The price structure arising from the quality of housing equipment is shown in the following table.

Table 4.7: Impact of Quality of Equipment on German housing prices

	Sales Prices		Rental Prices	
Quality of Equipment (level)	Price Premium/ Discount	Significance of Coefficient	Price Premium/ Discount	Significance of Coefficient
Simple Standard	- 23.96 %	***	- 10.66 %	***
Normal Standard	<i>Benchmark</i>			
Superior Standard	+ 26.21 %	***	+ 17.26 %	***
Luxury Standard	+ 51.62 %	***	+ 35.55 %	***

All non-linear constituents the model (reflected by thin-plate spline functions with a number of knots automatically adjusted to the respective scale on the software side, as shown in the following graphs) of are highly significant at < 0.1 % level (***)

We find that properties of up to 5 rooms generate price premiums, while properties with 6 or more rooms in contrast deliver price discounts of up to 20 % across building typologies. We review this information in the light of additional insights on the living area. For that variable, the study complementarily confirms higher prices for smaller living areas (as typical, for instance, in student housing, shared apartments or micro housing) as well as for very large living areas of more than 100 square meters. At

around 50 square meters, housing generates lowest sales prices, as shown in the following illustrations.

Figure 4.7a/4.7b: The Price Spline Function of rooms and area in housing sales markets

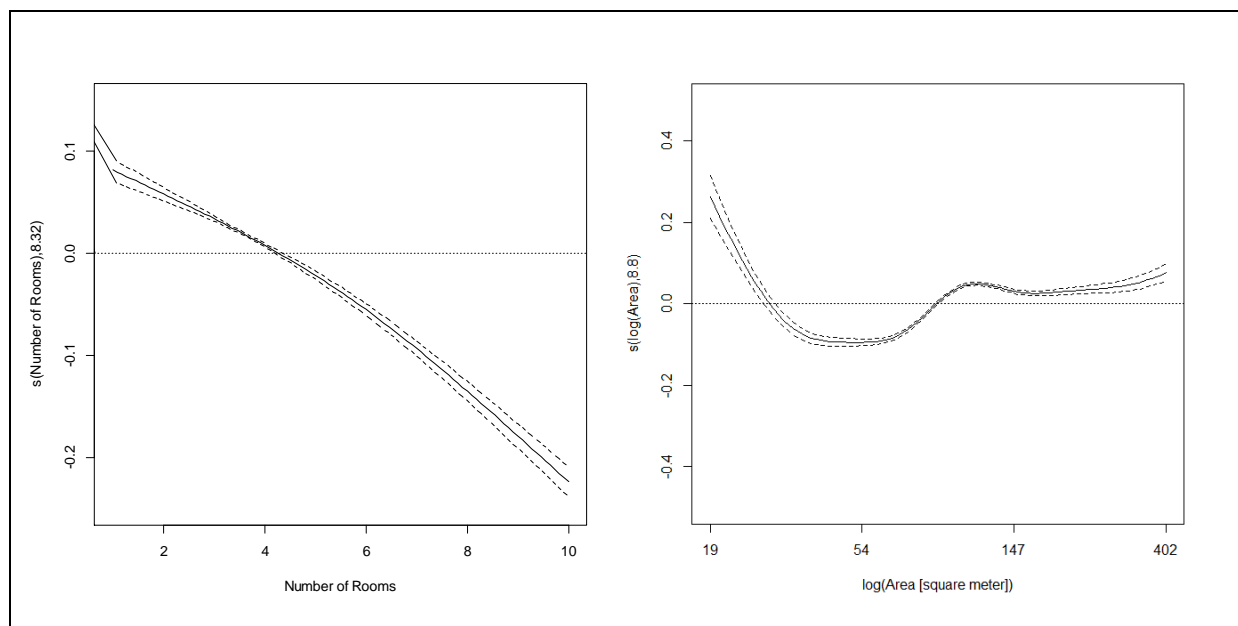
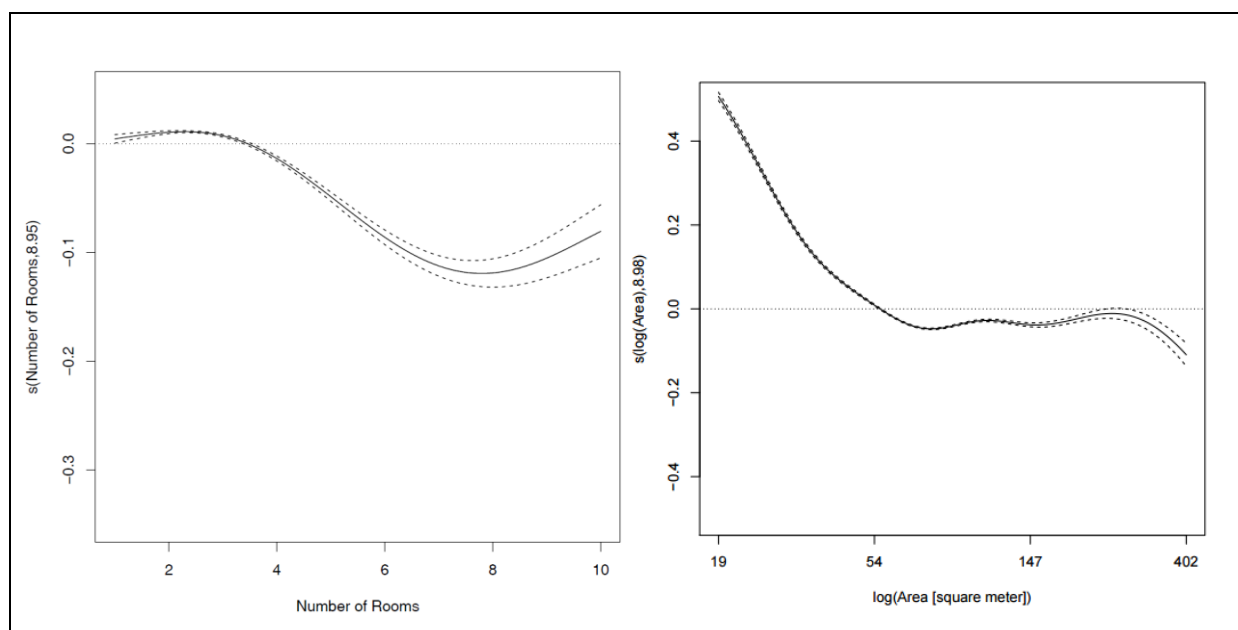


Figure 4.8a/4.8b: The Price Spline Function of rooms and area in rental housing markets

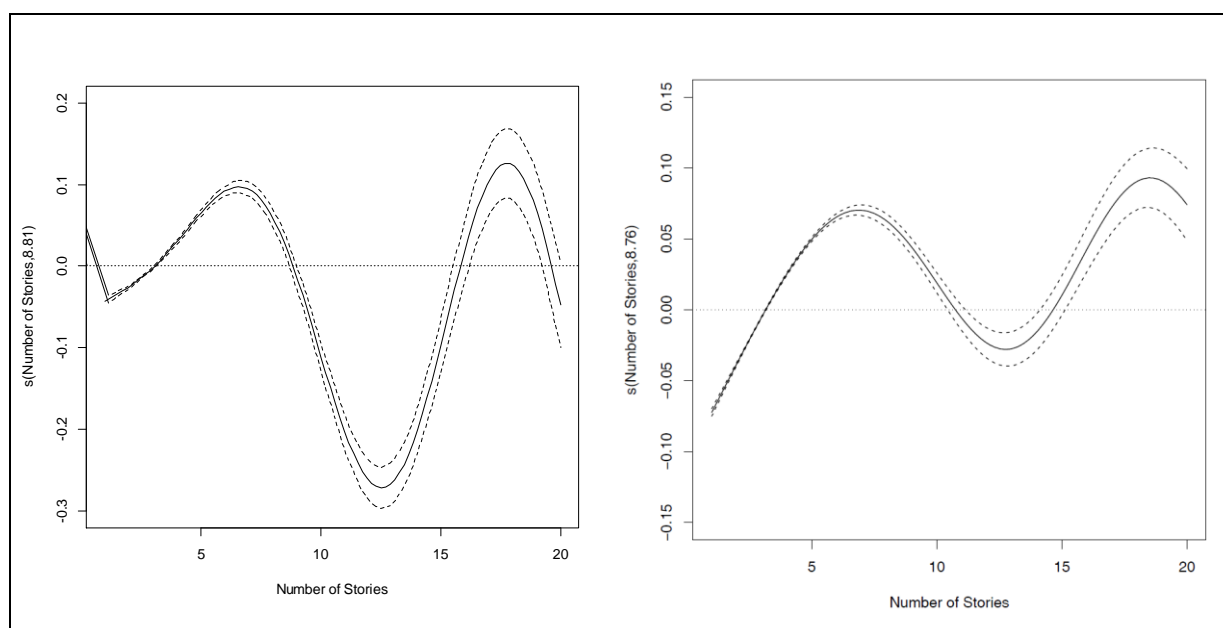


In terms of rooms and living area, rental markets draw similar patterns, although especially the impact of number of rooms happens on a smaller scale for small housing

than on sales markets. In terms of area sizes, the appreciation for extensively large property cannot be observed on rental markets, although it is indeed confirmed on sales markets. However, this may also be caused by the sale of multi-family houses, which are frequently traded as investment objects and therefore may realize price premiums.

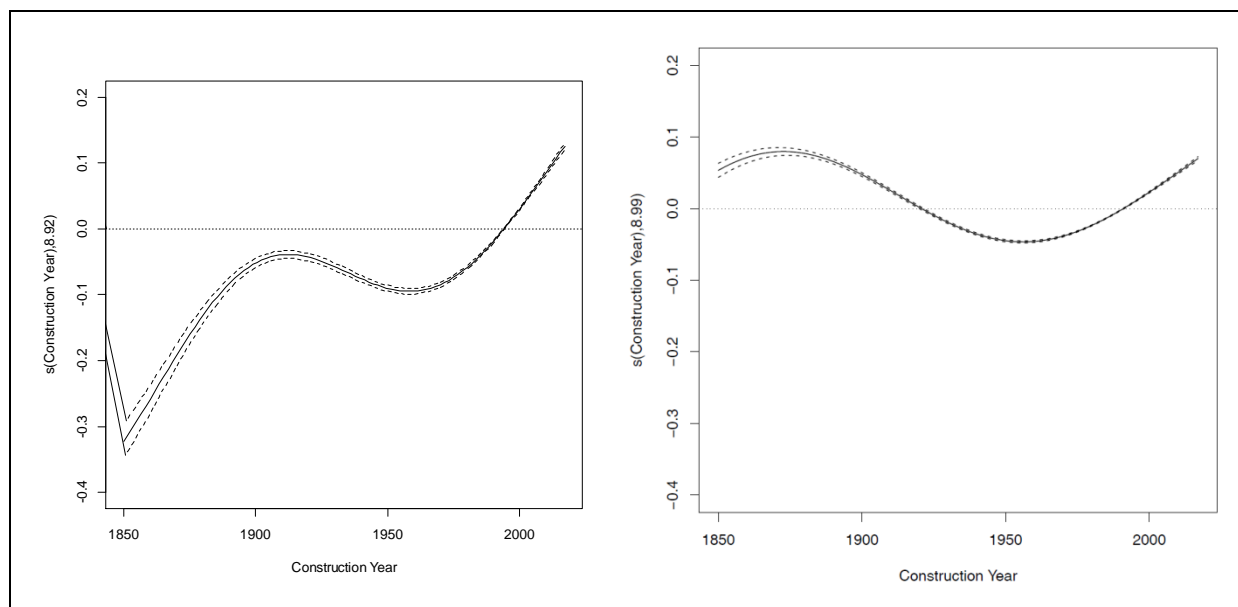
The following spline delivers a characteristic price pattern regarding the number of stories of the building. Houses with a higher number of stories come with higher prices, however, there is an illustrative gap between 8 and 15 stories – which is a typical height for a certain property type, known for lower quality and mass housing as ‘plattenbau’ in both German and English language. This clear gap can only be observed for sales markets: while rental markets do also show lower prices for living space in houses with 10 to 15 stories, the amplitude is significantly smaller. Houses of more than 15 stories come with a price premium in both sales and rental markets, again, which may be rather traded as locations for higher-price luxury penthouse apartments. However, these premiums are subject to higher uncertainty in estimates, as the following illustration shows.

Figure 4.9: The Price Spline Function of the number of stories in sales (left) and rental housing markets



Also in terms of the building age (construction year), very characteristic patterns could be observed. It is illustrated in the following spline.

Figure 4.10: The Price Spline Function of the construction year in sales (left) and rental housing markets



While new buildings generate significantly higher sales prices, also due to higher property quality and specifically increased building costs, broad differences are observed in existing buildings. Especially a war and post-war gap of quality housing is observable, c.p. showing lower prices. Art Noveau buildings between 1900 and 1920 however show lower discounts and are actually more expensive than properties from the 1940s-1970s. Interestingly, rental prices are tremendously smoother in terms of the construction year impact with effects between + 10 % and - 5 % in the time span between 1850 and 2000.

4.4. Conclusion and Discussion

Our study finds that

1. Housing markets incorporate progressive 'green' heating technology in pricing considerations and higher sales prices are demanded, if those technologies are on hand. This 'green premium' amounts to roughly 3 % c.p.
2. Also, a 'brown discount' is equally evident. This refers to those properties that explicitly advertise conventional heating technologies which are subject to technical obsolescence in the long term. The 'brown discount' amounts to approximately 4.2 % c.p.
3. The same pattern can be confirmed for rental housing markets. Here, we observe a heating technology-driven 'green premium' of 2.4 % c.p. on average and a 'brown discount' of approximately the same magnitude. We conclude that rental markets react smoother towards heating technology features than the investment and purchasing side.
4. There is a premium in sales prices of residential properties, which feature low energy consumption levels. The same is true for rental markets. In that sense, also general energy efficiency seems to 'pay off'.
5. Bringing both dimensions together, however, we see that low energy consumption levels alone seem to be only the necessary condition, but not the sufficient condition for generating sales or rent price premia in housing markets. The question, which heating technology is causing the low consumption levels, appears at least equally important.

Going beyond the specific research question raised, this study features more general insights and evidence on German housing markets from a large data sample. Selected aspects cover regional differences between Northern and Southern or rather Eastern and Western Germany. Also, quality of equipment or listed properties seem to cause highly significant results.

While specific limitations of the analysis are outlined at the end of this work, it appears expedient to contrast the findings in the light of existing findings from previous studies. Unfortunately, there is not a great quantity of comparable research with similar focus on heating technology and its impact on pricing in residential markets. The incorporation of technological aspects was limited to photovoltaic in related literature as reviewed in this paper. While Hoen et al., 2011, conclude that the property price premium they identified

should be explained by reduced utility bills from using photovoltaic technologies, this study and its results suggest that additional factors such as market development, market regulation as well as behavioral aspects may cause the price structure from different levels of technological progressiveness in heating.

In addition, there is a comprehensive body of existing literature with a majority of results directing to a 'green premium' of energy-efficiency features, which we analysed by energy consumption levels as control variables and which we can confirm, also. In this context, the identified amount of the price premium is comparable to previous findings, while this study additionally accounts for the specific non-linearity of price patterns. Peak and floor values of the premium and discount, however, seems in line with other studies such as Fuerst and McAllister, 2011, Cajias and Piazzolo, 2013 or Fuerst et al., 2015.

In terms of the general discussion on housing and its role for climate change, energy efficiency or retrofitting, this paper aims to contribute one further input. Looking at the core question of the study (being the price impact of heating technology) and its innovation specifically, it becomes obvious that a differentiation between building-related and system-related measures should be made when estimating prices in residential real estate. This is of particular importance, as a lot of renovation activity is not performed holistically, but rather focusing on only either building-related measures such as insulation or system-related measures such as replacing a boiler in the home. However, both effects may be adverse, as this study has shown: we found that properties with generally good energy-efficiency (e.g. due to sealed building envelopes) may still experience a brown discount if the heating system integrated does not reflect an equally good standard.

Moving forward, the results delivered may advise real estate decision making in several ways: first, they might be suitable to develop an addition to existing theory on 'green premiums' and 'brown discounts' by bringing forward the argument that building renovation should be performed in its entirety by rather suggesting a price premium for performing single components of a renovation package. Secondly, the results should encourage policy-makers to start or to continue promoting building renovation in a connected view in order to avoid the above-mentioned one-dimensionality of renovation: consequently, public funds should be assigned to both building- as well as system-related measures and to encourage both an improvement of building substance as well as technical property equipment, as the latter is the driving consumer of energy in the operation of properties. And ultimately, the results may advise appraisers and investment practitioners to identify price determinants on a more

detailed level, as the effects may be adverse and the expected 'green premiums' may be unachievable by the investment due to only partial measures performed.

Further research

To gather further insights into the field of this study and to expand related existing research on the market reaction patterns and behavior of the housing market, we suggest to perform analysis covering a longer time span. This should provide further evidence on how the effect of energy efficiency and the heating type develops over time. We might expect that the amounts of 'green premium' and 'brown discount' deviate between years. Also, changes in energy standards may bias the role of energy efficiency throughout the years (low-energy buildings may lose their deluxe appearance in the market over time, given increasing technological standards and regulation). In addition, we suggest to contrast the identified premium and discount to the differences in production and installation costs of respective 'new' or 'old' technology. Also, adding a distinction between consumption-driven energy performance certificates and demand-driven energy performance certificates might refine the results on the general green premium from energy efficiency: with that approach, a difference could be made between ordinary baseline heating demand from the property and possibly additional energy consumption caused by the occupant's behavior.

Limitations

This study is subject to certain limitations in methodology and the data set applied: firstly, an omitted variable bias is possible. We assume this could be the case with regard to a variable on the status of the property (e.g. maintenance situation) or the building type. At the same time, some of the integrated variables may show a certain consonance with other variables. If multicollinearity should be on hand to an extent, where certain variables should actually influence others, the standard errors may mis-estimated. However, the expected values, should remain valid and unbiased. Furthermore, as we integrate asking prices of the properties and have no information on the actual transaction price, a difference should be made between willingness-to-pay and "willingness-to-demand". We analyze with the implicit assumption that landlords can enforce their asking price, which should be the case in the clear majority, but not all situations. Throughout the large sample size, this may constitute an upward bias in property prices. And ultimately, the set-up of heating technology baskets is

based on valid assumptions, but might be designed in other compositions in a rather interdisciplinary approach. As soon as not only cost- and market-based considerations, but also clearly technologically driven standards would be integrated, the compositions of what is treated 'green' or 'brown' might be subject to discussion.

4.5. References

- Aroul, Ramya and J. Hansz (2012): *The Value of "Green": Evidence from the First Mandatory Residential Green Building Program*. Journal of Real Estate Research, Vol. 34, No. 1, pp. 27-50.
- Cajias, Marcelo, F. Fuerst and S. Bienert (2016): *Are energy efficiency ratings ignored in the German housing market? Evidence from a large-sample hedonic study*. Presented at the European Real Estate Society Conference, Regensburg, June 8th – 11th, 2016.
- Cajias, Marcelo and D. Piazzolo (2013): *Green performs better: energy efficiency and financial return on buildings*. Journal of Corporate Real Estate, Vol. 15, No. 1, pp.53-72.
- Chegut, Andrea, P. Eichholtz, and N. Kok (2014): *Supply, Demand and the Value of Green Buildings*. Urban Studies, Vol. 51, No. 1, pp. 22-43.
- Dinan, Terry and J. Miranowski (1989): *Estimating the implicit price of energy efficiency improvements in the residential housing market: A hedonic approach*. Journal of Urban Economics, Vol. 25, No. 1, pp. 52-67.
- Eichholtz, Piet, N. Kok, and J. Quigley (2010): *Doing Well by Doing Good? Green Office Buildings*. American Economic Review, Vol. 100, No. 5, pp. 2492-2509.
- Federal Statistical Office (2018): *Housing Prices of the Länder*, https://www.statistik-bw.de/Statistik-Portal/en/en_inhalt21.asp (last accessed April 29th, 2018)
- Fuerst, Franz and P. McAllister (2011): *The impact of Energy Performance Certificates on the rental and capital values of commercial property assets*. Energy Policy, Vol. 39, No. 10, pp. 6608-6614.
- Fuerst, Franz, P. McAllister, A. Nanda, and P. Wyatt (2015): *Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England*. Energy Economics, Vol. 48, March 2015, pp. 145-156.
- Fuerst, Franz, E. Oikarinen and O. Harjunen (2016): *Green signaling effects in the market for energy-efficient residential buildings*. Applied Energy, Vol. 180, pp. 560-571.
- Gilmer, Robert (1989): *Energy labels and economic search: an example from the residential real estate market*. Energy Economics, Vol. 11, No. 3, pp. 213-218.

- Hoen, Ben, R. Wiser, P. Cappers, and M. Thayer (2011): *An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in California*. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.
- Hyland, Marie, R. Lyons and S. Lyons (2013): *The value of domestic building energy efficiency – evidence from Ireland*. *Energy Economics*, Vol. 40, November 2013, pp. 943-952.
- Lacquatra, Joseph (1986): *Housing market capitalization of thermal integrity*. *Energy Economics*, Vol. 8, No. 3, pp. 134-138.
- Leopoldsberger, Gerrit, S. Bienert, W. Brunauer, K. Bobsin, and C. Schuetzenhofer (2011): *Energising Property Valuation: Putting a Value on Energy-Efficient Buildings*, *The Appraisal Journal*, Spring 2011, pp. 115-125.
- Mense, Andreas (2016): *The Value of Energy Efficiency and the Role of Expected Heating Costs*. Presented at the European Real Estate Society Conference, Regensburg, June 8th-11th, 2016.
- Miller, Norm, J. Spivey and A. Florance (2008): *Does Green Pay Off?* *Journal of Real Estate Portfolio Management*, Vol. 14, No. 4, pp. 385-400.
- Nevin, Rick and G. Watson (1998): *Evidence of rational market valuations for home energy efficiency*. *The Appraisal Journal*. Vol. 66, No. 4, pp. 401-409.
- Newell, Graeme, J. MacFarlane, and R. Walker (2014): *Assessing energy rating premiums in the performance of green office buildings in Australia*. *Journal of Property Investment & Finance*, Vol. 32, No. 4, pp. 352-370.
- Pivo, Gary and J. Fisher (2010): *Income, Value, and Returns in Socially Responsible Office Properties*. *Journal of Real Estate Research*, Vol. 32, No. 3, pp. 243-270.
- Reichardt, Alexander, F. Fuerst, N. Rottke, and J. Zietz (2012): *Sustainable Building Certification and the Rent Premium: A Panel Data Approach*. *Journal of Real Estate Research*, Vol. 34, No. 1, pp. 99-126.
- Wameling, Tim (2010): [„Property Values and Energy Demand. The impact of energetic quality on residential values.“]. Available in German.
- Wood, Simon (2013): *On p-values for smooth components of an extended generalized additive model*. *Biometrika*, Vol. 100, No. 1, pp. 221-228.

4.6. Annex 1 – Purchasing Prices (Hedonic Regression Output)

Table 4.8: Full Output – Sales Price Model Estimate

```

Parametric coefficients:

              Estimate Std. Error t value Pr(>|t|)
(Intercept)    7.588535   0.010892  696.707 < 2e-16 ***
balconyYes      0.098725   0.003645   27.082 < 2e-16 ***
federal_stateBavaria  0.013572   0.010534    1.288 0.197594
federal_stateBerlin  0.021948   0.036126    0.608 0.543481
federal_stateBrandenburg -0.380063   0.033956 -11.193 < 2e-16 ***
federal_stateBremen  -0.152734   0.023861   -6.401 1.55e-10 ***
federal_stateHamburg  0.462555   0.023205   19.934 < 2e-16 ***
federal_stateHesse    0.043998   0.010340    4.255 2.09e-05 ***
federal_stateMecklenburg-Vorpommern -0.371517   0.028415 -13.075 < 2e-16 ***
federal_stateLowerSaxony -0.280086   0.017752 -15.777 < 2e-16 ***
federal_stateNorthRhineWestphalia -0.097091   0.014837   -6.544 6.02e-11 ***
federal_stateRhinelandPalatine -0.174044   0.009784 -17.789 < 2e-16 ***
federal_stateSaarland -0.154636   0.018376   -8.415 < 2e-16 ***
federal_stateSaxony   -0.257061   0.025325 -10.151 < 2e-16 ***
federal_stateSaxonyAnhalt -0.671690   0.024305 -27.636 < 2e-16 ***
federal_stateSchleswig-Holstein -0.107823   0.024120   -4.470 7.82e-06 ***
federal_stateThuringia  0.074962   0.020070    3.735 0.000188 ***
factor(urban_center)1  0.169896   0.004857   34.978 < 2e-16 ***
listedYes       0.178603   0.007935   22.509 < 2e-16 ***
greenheating_classBrown -0.042286   0.004635   -9.123 < 2e-16 ***
greenheating_classGreen  0.030613   0.003015   10.154 < 2e-16 ***
propertytypeApartment  -0.101426   0.004652 -21.803 < 2e-16 ***
equipmentqualitySimple  -0.239569   0.005218 -45.914 < 2e-16 ***
equipmentqualitySuperior  0.262132   0.002379  110.204 < 2e-16 ***
equipmentqualityLuxury   0.516192   0.004647  111.093 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

              edf Ref.df      F    p-value
s(logArea)      8.828  8.991  147.17 <2e-16 ***
s(numberofstories) 8.807  8.979  147.60 <2e-16 ***
s(constructionyear) 8.916  8.997  314.39 <2e-16 ***
s(logEnergyConsumption) 8.930  8.998   64.46 <2e-16 ***
s(numberofrooms)   8.319  8.807  120.90 <2e-16 ***
s(geox_coord,geoy_coord) 28.966 29.000 1329.20 <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.613   Deviance explained = 61.4%
GCV = 0.12221   Scale est. = 0.12213   n = 141859

```

4.7. Annex 2 – Rental Prices (Hedonic Regression Output)

Table 4.9: Full Output – Rental Price Model Estimate

Parametric coefficients:

	Estimate	Std. Error	t value	Pr(> t)	
(Intercept)	2.0316933	0.0076730	264.784	< 2e-16	***
balconyYes	0.0480451	0.0011658	41.211	< 2e-16	***
federal_stateBavaria	-0.1137747	0.0067553	-16.842	< 2e-16	***
federal_stateBerlin	-0.1725954	0.0151584	-11.386	< 2e-16	***
federal_stateBrandenburg	-0.3907484	0.0139636	-27.983	< 2e-16	***
federal_stateBremen	0.1092010	0.0115977	9.416	< 2e-16	***
federal_stateHamburg	0.4373907	0.0115083	38.007	< 2e-16	***
federal_stateHesse	0.0269330	0.0058824	4.579	4.68e-06	***
federal_stateMecklenburg-Vorpommern	-0.1995335	0.0142135	-14.038	< 2e-16	***
federal_stateLowerSaxony	0.0369595	0.0092826	3.982	6.85e-05	***
federal_stateNorthRhineWestphalia	0.0008537	0.0078297	0.109	0.913173	
federal_stateRhinelandPalatine	-0.1086328	0.0056283	-19.301	< 2e-16	***
federal_stateSaarland	0.0486285	0.0127895	3.802	0.000143	***
federal_stateSaxony	-0.2888919	0.0107897	-26.775	< 2e-16	***
federal_stateSaxonyAnhalt	-0.3864138	0.0105569	-36.603	< 2e-16	***
federal_stateSchleswig-Holstein	0.1377460	0.0120112	11.468	< 2e-16	***
federal_stateThuringia	-0.0444282	0.0099172	-4.480	7.47e-06	***
factor(cor_class)1	0.0950787	0.0018170	52.327	< 2e-16	***
listedYes	0.0564316	0.0041894	13.470	< 2e-16	***
greenheating_classBrown	-0.0243893	0.0029173	-8.360	< 2e-16	***
greenheating_classGreen	0.0241706	0.0016134	14.981	< 2e-16	***
propertytypeApartment	-0.1075493	0.0027255	-39.460	< 2e-16	***
equipmentqualitySimple	-0.1065720	0.0039168	-27.209	< 2e-16	***
equipmentqualitySuperior	0.1725560	0.0010662	161.843	< 2e-16	***
equipmentqualityLuxury	0.3555090	0.0025664	138.524	< 2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value	
s(logArea)	8.985	9.000	1740.68	<2e-16	***
s(numberofstories)	8.755	8.965	545.89	<2e-16	***
s(constructionyear)	8.995	9.000	503.22	<2e-16	***
s(logEnergyConsumption)	8.805	8.987	118.83	<2e-16	***
s(numberofrooms)	8.950	8.999	75.67	<2e-16	***
s(geox_coord,geoy_coord)	28.995	29.000	2374.18	<2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) = 0.585 Deviance explained = 58.6%
GCV = 0.054243 Scale est. = 0.054223 n = 266583

5. Conclusion

This dissertation has elaborated on theoretical models and empirical evidence regarding real estate market behavior and impact patterns following changes in interest rates and other macroeconomic determinants, in terms of present flood risk, and in terms of progressive versus obsolescent heating technologies.

The following sub-section summarizes the results of the three studies included, before concluding this work by giving an outlook to possible further research directions and touching on general limitations in the context of scientific analysis within the selected research fields.

5.1. Executive Summary

Office properties through the interest cycle: Performance impact and economic sustainability in Germany

Even years after the Lehman breakdown, the investment industry – including real estate – is still under the impression of the financial crisis and experience a long-lasting low-interest rate phase as an economic stabilization mechanism. However, affordable financing also led to investment pressure and connected price increases as well as decreasing yields in real estate and other asset classes. The aim of this paper was to estimate the interconnection of office rents as well as capital values and several underlying macroeconomic determinants, ultimately focusing on the research question whether an instant and significant increase in the prime rate level would impact office rents and values as office performance components and how this impact would develop over time. The underlying dataset comprised a time series of several macroeconomic factors as well as office performance information provided by the Association of German Pfandbrief Banks (vdp), all on a quarterly basis. Estimations using vector-autoregressive models delivered a moderately positive development of both indicators despite the increase of interest levels. The impulse-response of capital values suggests a time lag of approximately 1.5 years before negative effects occur. In comparison to other macro-economic determinants, the interest level causes stronger impulse-responses than the general economic environment (measured by GDP growth), but all other macro-economic determinants provoke stronger reactions. Ultimately, office rents could be confirmed to be very robust against changes in economic determinants throughout the total consideration period of 6 years. This

might be explained by rent increase mechanisms that create increases in cash flow yields automatically and successively over time.

How flood risk impacts residential rents and property prices – empirical analysis of a German property market

Extreme weather events have increased significantly in terms of frequency, but also intensity. And indeed, flooding today depicts the second-most frequent cause for elementary damage in Germany (just after storms) with major implications for property owners or the insurance industry. This paper aims to quantify the impact of 100-year flood risk on both property rents and values in Germany, exemplified by the market of the historic city of Regensburg, and therefore supports investors in understanding market behavior patterns in both a rental and investment context. Estimations are based on two Generalized Additive Models (GAMs) for rents and purchasing prices with spatial components and under inclusion of both typical property characteristics (as control variables) and a 100-year flood risk parameter in order to isolate its effect on the rents and property price structure. The analysis is performed on the basis of a 4-years data set of more than 16,500 observations. The analysis shows that flood risk is a highly significant parameter when estimating both the rent as well as the sales price model. Also, it is delivered that purchase prices for one square meter of living area are, on average, 299 EUR lower if the property is located in the flood risk zone. In addition, also rental markets come with a respective, but rather low, discount. Being the first study that aims to empirically test and to quantify the impact of flood risk on property rents and purchasing prices in Germany,¹³ it provides transparency to investors in terms of the reaction patterns of a German residential market regarding flood risk location features.

Does ‘clean’ pay off? Housing markets and their perception of heating technology

Previous research has found that the energy consumption of properties affects achievable rent or purchasing prices on real estate markets. ‘Green premiums’ for higher quality in energy efficiency and energy consumption have been observed in terms of housing sales as well as rental prices. However, previous research has not made an explicit distinction between green effects from building-related measures (such as envelope insulation) and system-related measures (concerning heating technology). This study extends the existing body of knowledge

¹³ Related research has been performed for the United States, Ireland and New Zealand and largely refers to event-driven work; existing research in a German-speaking context is rather conceptual in the context of property valuation.

by raising and answering the question whether the type of heating system in the property is a significant driver of green price premiums, too. To elaborate a profound and contemporary answer to his, large-sample geo-additive regression analyses based on more than 400,000 observations covering German residential properties in 2015 is performed. The study finds that, first and foremost, the heating system indeed shows significant explanatory importance for measuring housing rents and purchasing price. Secondly, it finds that it makes a difference whether clean 'green' technologies are implemented or whether 'brown' technology with fossil energy sources is on hand. Ultimately, it concludes that while low energy consumption indeed comes with a price premium, this needs to be interpreted together with the property's heating type, as housing markets seem to outweigh the 'green premium' by 'brown discounts' if low energy consumption figures are powered by fossil energy.

5.2. Final Remarks and Outlook

Property values and prices are indicative of real estate market behavior. In a very condensed form, they reflect market sentiment, strength of demand or quality of supply. And although generalizability may be reduced with price information being in an appraised or demand-focused format, they contain price-building patterns and, therefore, facilitate the revelation and analysis of price determinants. In this context, this thesis has postulated the superior aim of creating the basis for a better understanding of value drivers and their impact patterns in a real estate environment. Scientific, empirical analysis in this thesis has aimed to decompose market behavior into value and price drivers and to estimate the effects of certain contemporary phenomena in terms of pricing patterns.

Society and the economy currently face major challenges in managing climate change and extreme weather events as well as sustainable economic development in times of turbulent macroconditions. This thesis has delivered insights into the role of macroeconomic as well as ecological and climatic developments for real estate as an asset class and as an industry. To some investors, real estate may suggest stability in price and values as well as a certain level of robustness. However, this depicts only a narrow and limited perspective, as real estate related decisions and market activities also may be associated with causing the latest financial crisis and with both resource consumption and climate change. Therefore, changes in macroeconomic determinants, in extreme weather events as one form of changes in climatic development, as well as the changes in technological standards regarding heating systems and

a related conservation of resources depict the framework of research fields, in which three areas of study were defined and selected for elaboration in the specific context of real estate.

In addition to the compilation and critical evaluation of existing literature, the three studies contained in this work have contributed to real estate research by delivering a comprehensive body of empirical findings, which was outlined in the executive summary at chapter 5.1 as well as the respective summaries of sections 2 to 4.

Above and beyond these findings, the studies have also been innovative and original in terms of the following empirical applications or methodological approaches:

1. Study no. 1 depicted the first impulse-response analysis of office markets in Germany. Incorporating several macro-determinants of real estate, including the prime interest rate, it generated insights into market reaction patterns towards fundamental changes in the economic surrounding.
2. Study no. 2 has delivered the first empirical analysis of the price impact patterns from an increased flood risk for a German case ever. In that sense, the study also added to existing theoretical studies on vulnerability and expected damages from extreme weather events for the first time.
3. Study no. 3 has exceeded existing linear and radial assumptions in logics for identifying 'urban centers' (also known as 'Central-Business Districts' in other work) by utilizing actual land use data, which was collected in *CORINE* as an EU-supported project. This has defined urban areas more precisely than in preceding literature, as also non-linear or non-radial urban structures could be reflected, and urban areas could be distinguished from rural areas with a higher level of accuracy.

5.2.1 General challenges of empirical real estate research (in Germany)

And while the studies and results may be suitable to support several parties, including property appraisers or investors, in making ecologically reasonable and economically sustainable decisions, some general limitations should be considered when interpreting the results in the context of the respective research field.

From a methodological point of view, multivariate methods come with the possibility of an omitted-variable bias or multicollinearity. Existing studies outline the dual role of possible explaining variables, including co-movements (but only indirect linkage) of several impact

factors. In the studies presented, this should be considered when focusing on the interplay of interest rates as well as other macro-economic determinants for office price patterns, the role of water as both an amenity as well as a risk to housing demand, as well as the existence of price-building factors on several geo-structural levels (e.g. price effect of state-level components such as land transfer tax vs. the price effect on x-/y-coordinate level revealing granular spatial effects).

The probably biggest limitation in (German) real estate research is the scarcity of reliable data, specifically the lack in (public) availability as well as in currency. Analysis largely depends on private datasets that themselves come with certain constraints, as they cover only certain market segments, limited geographical coverage, only certain time frames or have limited expressiveness, as they main contain erroneous entries in raw format.

Also, specifically transaction-based information is not generally made available in order to examine actual rental or purchasing prices – contrary to, for instance, housing markets in the United States, where address-level estimates are available through privately operated, publicly accessible platforms, such as “Zillow”, delivering information on property characteristics as well as facilities and interior fit-out, past sales prices, tax assessments and benchmarking with circumjacent properties in the U.S.

5.2.2 Research results in a broader context

With the comprehensive body of knowledge and detailed empirical insights gathered in this dissertation, it appears expedient to align them within a context of existing research output as well as a “bigger picture” in general. Which additional perspective can be derived from this thesis in terms of real estate research and practice?

Going forward, both real estate research and practice can derive additional perspectives from this thesis.

1. With macroeconomic framework conditions being what they are as a consequence of the financial crisis, German office markets appear to be a “safer haven” than other investment alternatives at this point. However, longer-term estimates on the interplay of these conditions and property prices could level the fact that German time series on commercial property markets are comparably short. Also, the suggested methodology should be

extended to other significant asset classes, specifically housing, in order to determine whether patterns differ amongst B2B- and B2C-/C2C-driven markets.

2. As the risk for interest rate changes is not invariant over time, the investor sentiment may be subject to negative or overly positive expectations that cannot be justified by economic fundamentals and which exist for longer than the actual economic cycle phase. Especially, as risk hedging and fixation of interest levels gains importance in low-interest rate environments, commercial property portfolios may gain additional stability from low financing costs as operational expenses despite actual economic stability. This is additionally fueled by the long-term characteristic of office rent contracts as well as value protection mechanisms according to German law. In that sense, high income is ensured from past agreements, although high demand from positive economic environments may have disappeared in the meantime.
3. Research on the impact of extreme weather events in an economic context is currently very limited from an empirical point of view. While it delivers insights and a decision basis for policy making and industries such as insurances or housing investments in terms of flood risks, valuable additional perspectives could be generated from studies on the price impact of risk regarding other extreme weather events such as storms or drought.
4. In accordance with prior research results, this work has shown how awareness of ecological sustainability, measured by energy efficiency and resource conservation, can lever financial profitability in addition to social consciousness and political desire.
5. Not only are energy efficiency and “green attributes” of buildings ecologically required and politically desired, but they also can make sound commercial sense. Even if quick returns on green investments are not generally confirmed, the danger of commercial disadvantage from technological obsolescence is equally present and was confirmed by this work in the form of a “brown discount”.
6. In line with the empirical results presented, a holistic view at energetic optimization of property appears beneficial. While performing “small solutions” and thereby small steps also from a cost perspective, an overall improvement of both building-related constitution as well as system-related efficiency (including options utilizing renewable energy sources), should be treated the most “sustainable” solution in ecological, social and economic terms.